

Reduce lens-numbers by Phase-Fresnel-Lenses in a telecentric lens

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Phase-Fresnel-Lenses (PFL) enlarge correction opportunities in spherical lens systems by aspheric deformations and additionally by color correction. A special telecentric lens system of seven spherical glass lenses is replaced by a three PF-lens arrangement. The nominal optical performance of both systems is equivalent.

1 Introduction

PFL are well established in imaging lenses of several infrared wavebands, where they are called Kinoforms or sometimes Diffractive. The Phase-Fresnel-(PF)-structure modulates the smooth refracting air-glass-surface by concentric rings having a radius of about $h_{zj} \approx \sqrt{j} \cdot h_{z1}$ while h_{z1} is the inner zone radius and j the zone number. These zones become denser close to the clear aperture CA. The step height t_{PF} between zones is in the wavelength range (see Fig. 1).

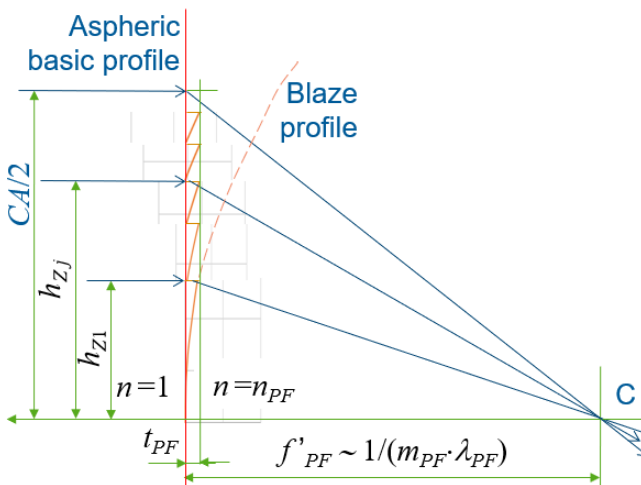


Fig. 1 Ray deviation by the PF-structure on an aspheric basic profile.

The PFL-naming [1] describes well the ray deviation without any diffraction effects. The blaze profile deviates rays additionally to the basic profile, it is ring-wise grounded on the aspheric basic profile with the step height of $t_{PF} = \frac{m_{PF} \cdot \lambda_{PF}}{|n_{PF} - 1|}$. This step height retains a phase shift of a multiple of λ in different PF-zones and conserves the interference in the image point.

All values defining t_{PF} are design-parameters of the PF-structure: m_{PF} the diffraction order (mostly =1), the design-wavelength λ_{PF} , and $n_{PF} = n(\lambda_{PF})$ the index of refraction of the PFL.

The point C corresponds with a diffraction maximum of the order m_{PF} at the wavelength λ_{PF} due to a circular ring structure having radii $h_{zj} = \sqrt{j} \cdot h_{z1}$. This maximum becomes visible at slim transparent rings and width black zones [2]. The blaze profile refracts the not diffracted (zero-order) rays to C. Its distance from the vertex of the basic profile could be also interpreted as the focal length f'_{PF} of the PF-structure.

2 PFL in the VIS-waveband

Commercially interesting applications are extreme Telephoto lenses like [3]. The PFL maintains the color correction of convergent front groups. The aspheric and achromatic COP-Hybrid-singlet [4] demonstrates technological skills using 240 zones j_{PF} at a minimal zone width $\delta h = 24\mu\text{m}$. Special industrial tasks offer some promising PFL-applications.

3 Dichromatic telecentric lens

The industrial use of both lenses in Fig. 2 is an object-side telecentric ray path with identical lateral magnification at two LED-wavelengths $0.594\mu\text{m}$ and $0.850\mu\text{m}$. The free object distance, the camera position and the camera itself, having a 5MP-imaging device with a pixel pitch of $3.45\mu\text{m}$, are given. The whole equipment works under clean room conditions better than 100.

The classic glass design (Fig. 2 left) consists of seven spherical glass lenses arranged in five groups. The five-lens-group around the aperture stop [5] ensures a tolerance friendly arrangement because this part has a positive Petzval curvature. It's impossible to achieve this result using Tessar-arrangements.

Surface	2	4	5
Vertex radius	-1376mm	9.551mm	-10.046mm
CA	31.6mm	5.34mm	4.85mm
j_{PF}	86	30	19
δh	95 μm	38 μm	49 μm

Tab. 1 PFL-data of different surfaces in Fig. 2 right

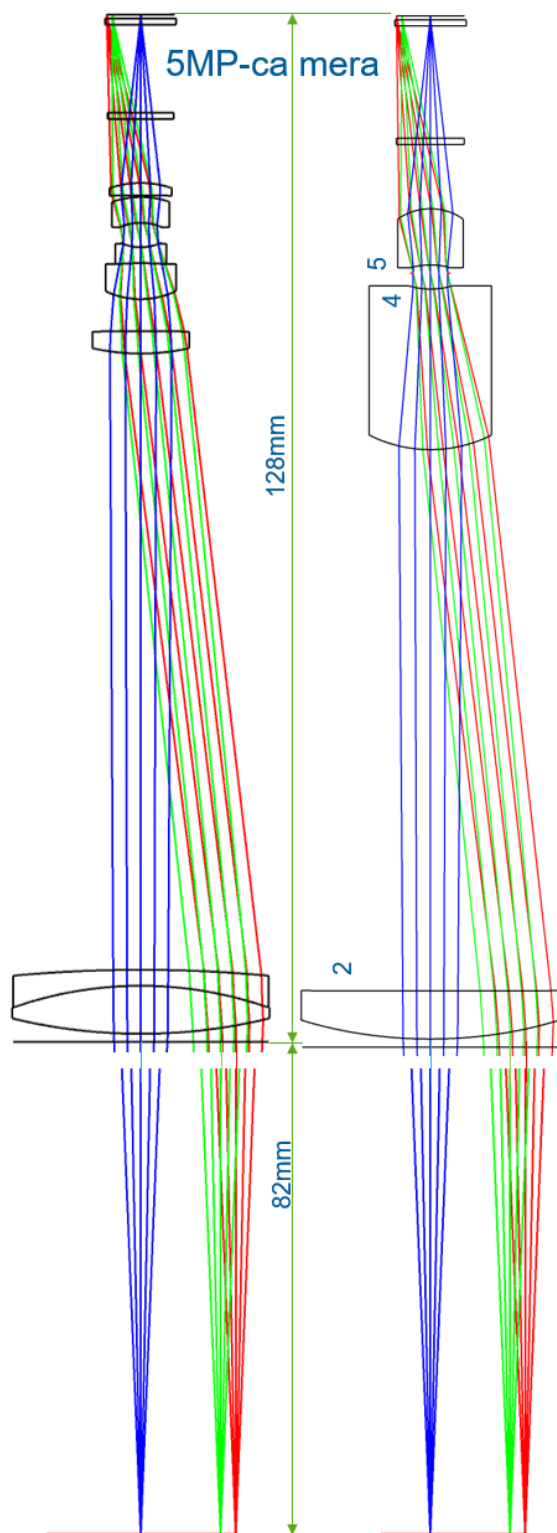


Fig. 2 Telecentric lenses with the same nominal optical performance in classic version (left) consisting of seven spherical glass lenses in five groups, and in three PF-lenses (right) consisting of organic glasses.

The alternative design (Fig. 2 right) consists of three PFLs, while the basic structure of the whole arrangement remains. A front group and lenses around the aperture stop ensure the object side telecentric ray path. All refracting surfaces have aspheric basic profiles. The inner surface 2 of the front

lens and both concave surfaces 4,5 around the aperture stop have additionally PFL-structures (see also Tab. 1).

4 Comparison of optical performance

The main customer-requirement is the object-side telecentric ray path at both LED-wavelengths. All principal rays in the aperture stop represent the gravity center of different ray bundles. Doing so, the telecentric error can be displayed by the slope of principal rays in the object space. Their absolute difference in reference to the ideal value zero will be averaged for 30%, 60%, and 100% field at both wavelengths. The telecentric error of the seven spherical glass lenses is $58.3\mu\text{rad}$. The three PFL-design reduces this value to $4.4\mu\text{rad}$. Additional degrees of freedom due to aspheric deformations allow this considerable improvement. In contrast, the resolution of both designs remains practically unchanged (see Fig. 3).

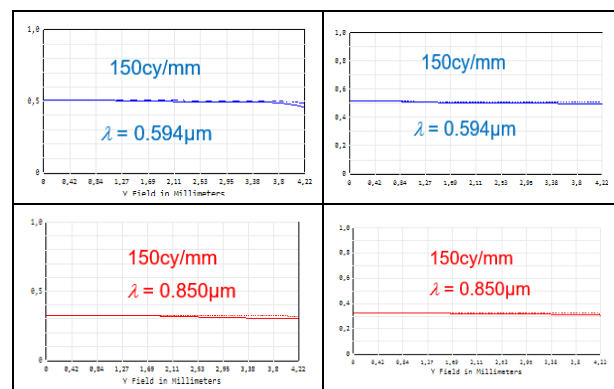


Fig. 3 MTF versus field at Nyquist frequency of the imaging device of seven spherical glass lenses (left) and three PF-lenses (right).

5 Conclusion

The application of PFL reduces considerably costs and efforts in this design example. Three design policies produce this success: 1. Keeping the basic arrangement of big front group ($f' \approx 100\text{mm}$) and small lenses around the aperture stop ($f' \approx 33\text{mm}$). 2. Respecting the correction opportunities and limits of aspheric deformations [6]. 3. PF-structures work without any impact on Petzval curvature.

References

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