# Advantages of customized optical design for aerial survey cameras

PHOWO 2009 - Handout

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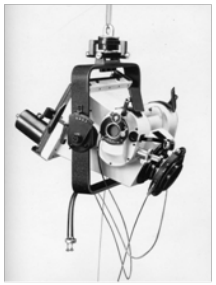
# Topics:

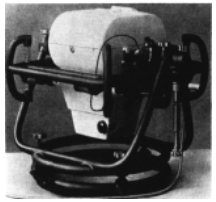
1) Historical Background
2) Customized Optical Design matching the Sensor Properties
3) Environmental Effects on Image Quality
4) As-Build-Performance simulated and measured
5) Conclusion

**Research & Technology Division**
**Historical Background – Aerial Survey Cameras made by Carl Zeiss**

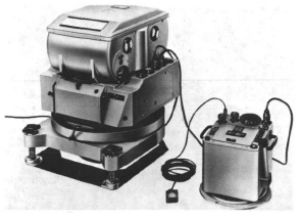


1910
Metric
Balloon
Camera

1916
Hand
held
Airplane
Camera

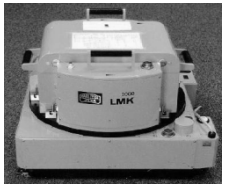


1922
*Analogue*
Aerial
survey
Camera
RMK C1



MRB
Carl Zeiss
Jena

1950s
*Analogue*
Aerial
survey
Camera
RMK



LMK
Carl Zeiss
Jena

1980s
*Analogue*
Aerial
survey
Camera
RMK TOP

2003
**Digital**
Mapping
Camera
DMC
**optics**

2009
**Digital**
Aerial
Survey
Camera
RMK-**D**
**optics**

# Topics:

1) Historical Background
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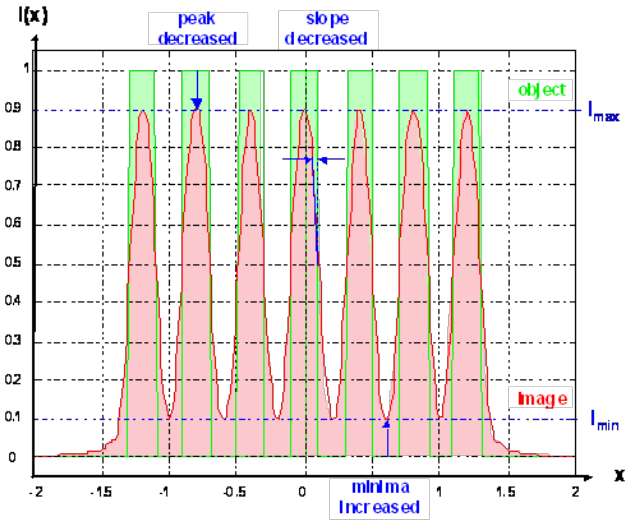
## Criteria : Modulation Transfer Function (MTF)



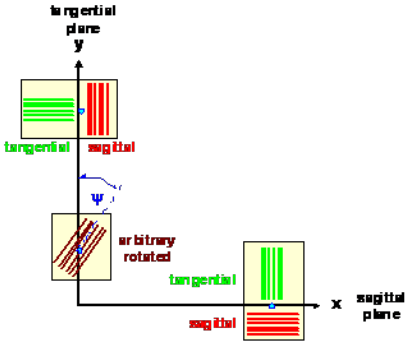

Modulation as measure for the ability to detect features

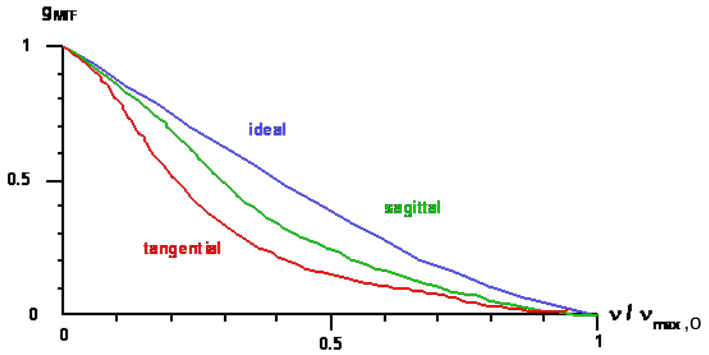
$V(v) = (I_{max}(v) - I_{min}(v)) \; / \; (I_{max}(v) + I_{min}(v))$

$v_{max,o} = 1/(F/\#\ \lambda)$ [LP/mm] (diffraction limited = ideal)

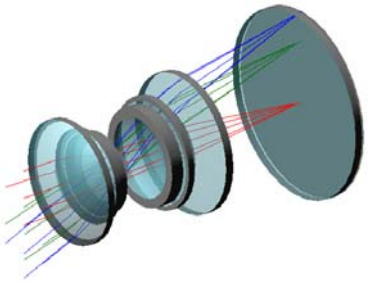
F/# = 4 $\lambda$ = 0.55/1000mm

$v_{max,o}$ = 450LP/mm

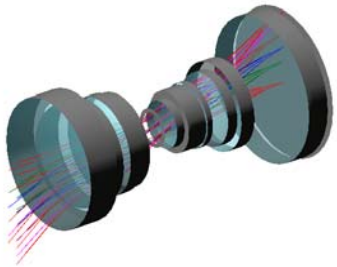


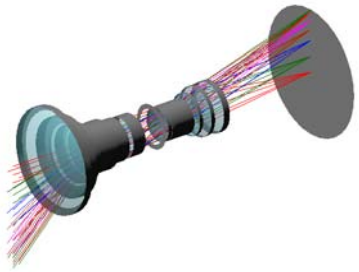
**Research & Technology Division**
**Customized Optical Design matching the Sensor Properties**



DMC Pan Lens
designed for
12um Sensor



RMK-D Lens
designed for
7.2um Sensor



Photographic
SLR Lens comparable
to RMK-D Lens

Compare designs with respect to resolution limit of digital sensor (Nyquist frequency).

$v_{max,s}$ =1/(2 Pixel size) [LP/mm]

Pixel size = 12/1000 mm
$v_{max,s}$ = 42LP/mm

$v_{max,s}$ =1/(2 Pixel size) [LP/mm]

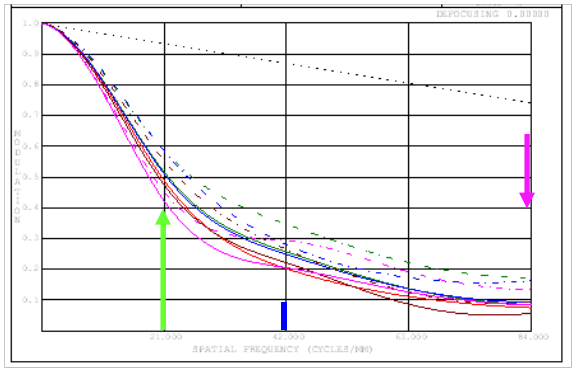
Pixel size = 7.2/1000 mm
$v_{max,s}$ = 70LP/mm

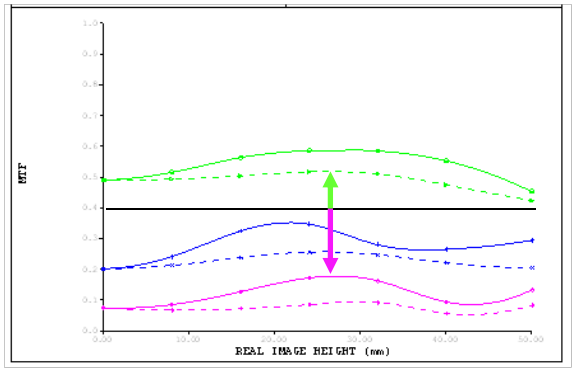
Design criteria > 40% @ $v_{max,s}$ / 2 => Visibility
Design criteria < 40% @ $v_{max,s}$ x 2 => Suppress Aliasing

**Research & Technology Division**
**Customized Optical Design matching the Sensor Properties**

Modulation Transfer Function (MTF) evaluated for 12um Sensor Pixel

DMC Pan Lens



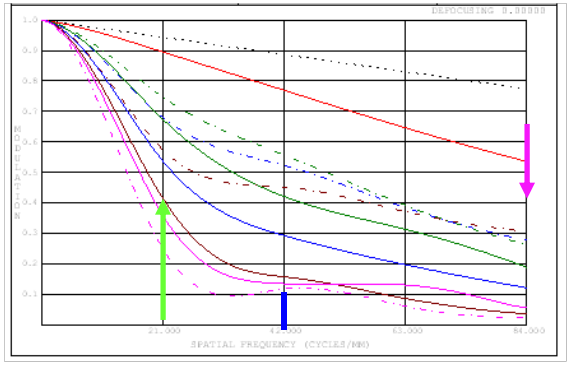

Nyquist / 2
21LP/mm

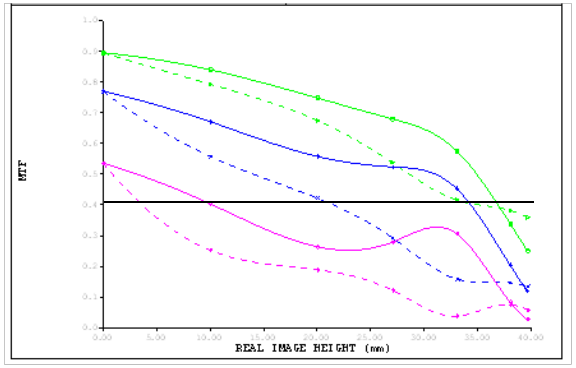
Nyquist
42LP/mm

Nyquist x 2
84LP/mm

Design criteria fulfilled for DMC Pan lens.

Photographic
SLR lens




Nyquist / 2
21LP/mm

Nyquist
42LP/mm

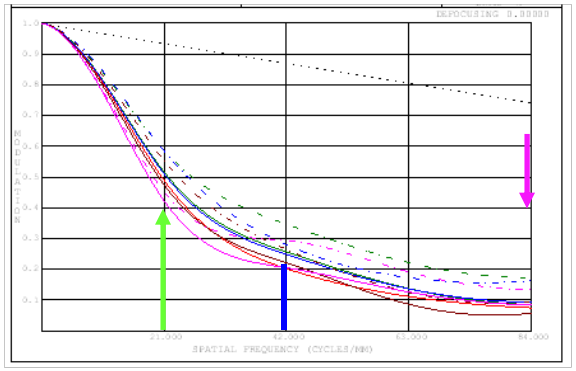
Nyquist x 2
84LP/mm

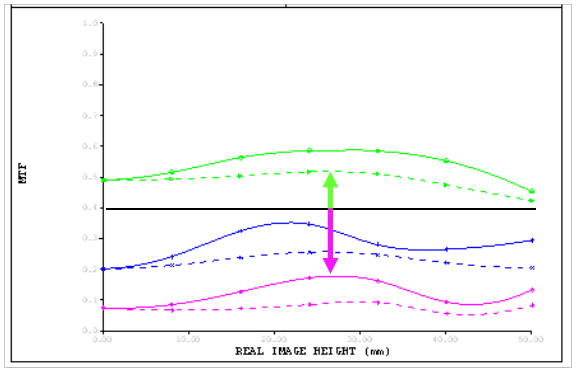
Typical photographic lens correction. Emphasis on center of field.
It is allowed for less correction effort at edge of field.

**Research & Technology Division**
**Customized Optical Design matching the Sensor Properties**

Modulation Transfer Function (MTF) evaluated for 12um Sensor Pixel

DMC Pan Lens



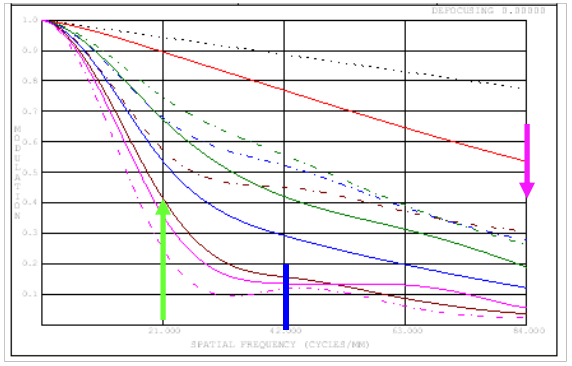

Nyquist / 2
21LP/mm

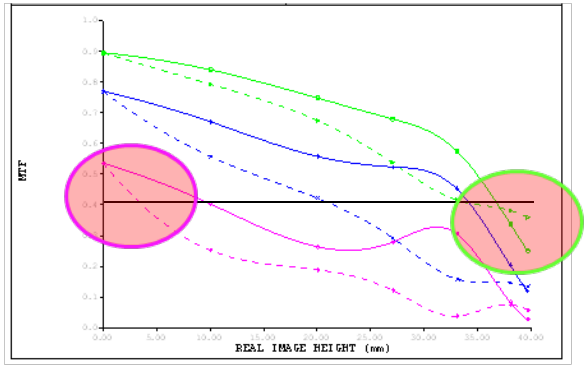
Nyquist
42LP/mm

Nyquist x 2
84LP/mm

Design criteria fulfilled for DMC Pan lens.

Photographic
SLR lens




Nyquist / 2
21LP/mm

Nyquist
42LP/mm

Nyquist x 2
84LP/mm

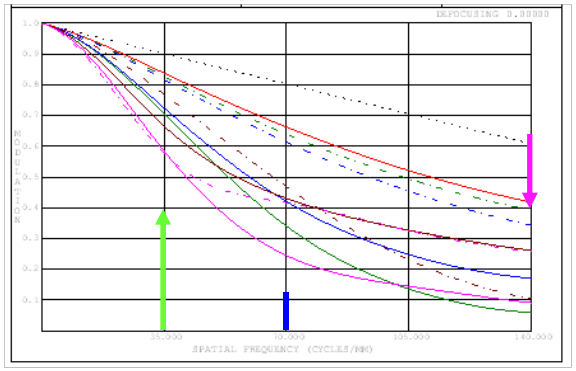
Visibility criteria only fulfilled within 80% of image field.
Aliasing criteria not fulfilled within center of image field.

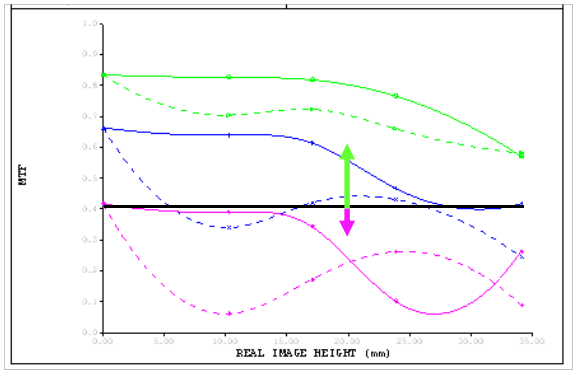
**Research & Technology Division**
**Customized Optical Design matching the Sensor Properties**

ZEISS

Modulation Transfer Function (MTF) evaluated for 7.2um Sensor Pixel

RMK-D Lens



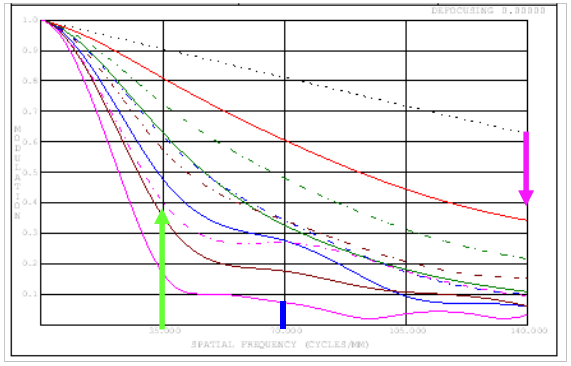

Nyquist / 2
35LP/mm

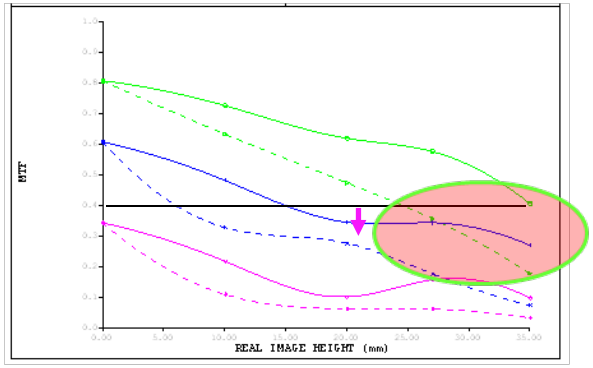
Nyquist
70LP/mm

Nyquist x 2
140LP/mm

Design criteria fulfilled for RMK-D lens.

Photographic SLR lens




Nyquist / 2
35LP/mm

Nyquist
70LP/mm

Nyquist x 2
140LP/mm

Design criteria only fulfilled within 70% of already reduced RMK-D image field.

**Research & Technology Division**
**Customized Optical Design matching the Sensor Properties**

Comparison customized design vs. standard photographic lens

+ Performance criteria fulfilled across entire field of view

+ Uniform Performance across the field of view

+ Performance matched to sensor with respect to sensor size, resolution and aliasing

- Photographic lens may **fulfill performance requirements of aerial survey camera systems only for reduced field of view or at lower speeds.**

- This is **not an issue for photography**, where the center of field of view is of most importance.

- It may however **limit the performance for photogrammetric applications**.

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1) Historical Background
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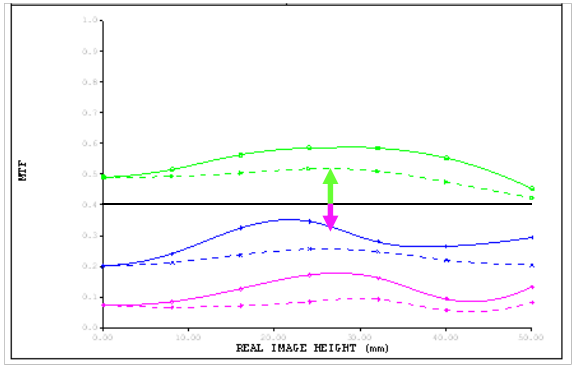
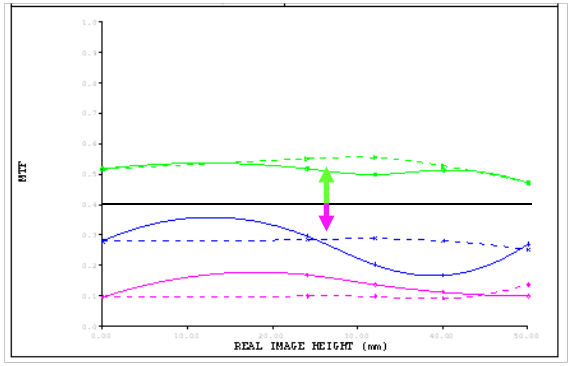
4) As-Build-Performance simulated and measured
5) Conclusion

**Research & Technology Division**
**Environmental Effects on Image Quality - Pressure**

Modulation Transfer Function (MTF) evaluated for 5000m height change

DMC Pan Lens



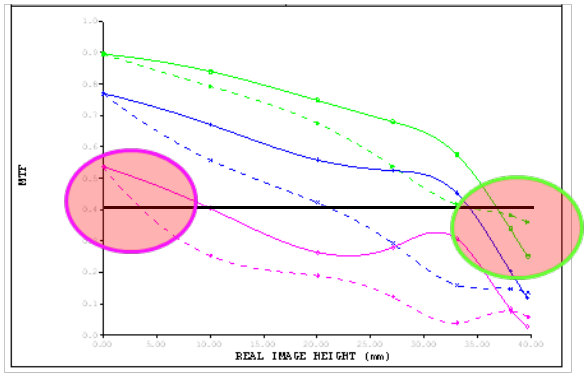

Nyquist / 2 21LP/mm

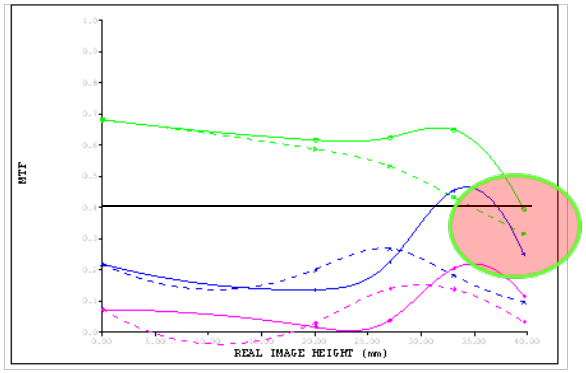
Nyquist 42LP/mm

Nyquist x 2 84LP/mm

Design criteria fulfilled for DMC Pan lens over a very large pressure range. Visibility remains unchanged.

Photographic SLR lens




Nyquist / 2 21LP/mm

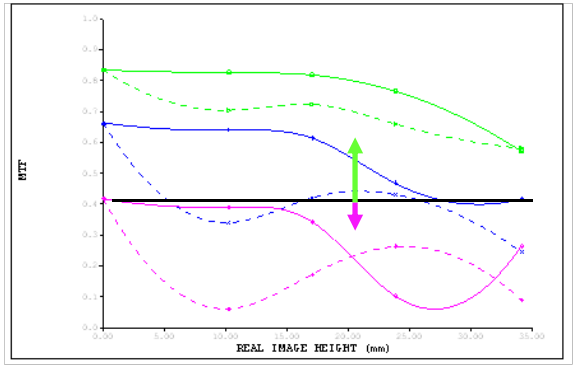
Nyquist 42LP/mm

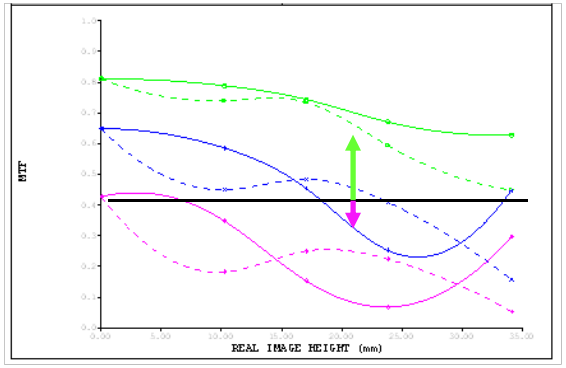
Nyquist x 2 84LP/mm

Design criteria only fulfilled within 80% of image field.
Visibility changes dramatically with change in pressure.

Modulation Transfer Function (MTF) evaluated for 5000m height change

RMK-D Lens



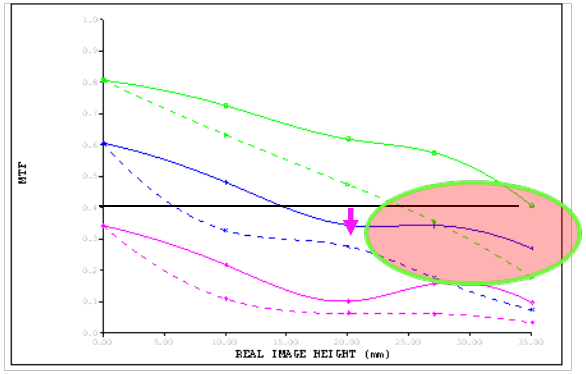

Nyquist / 2 35LP/mm

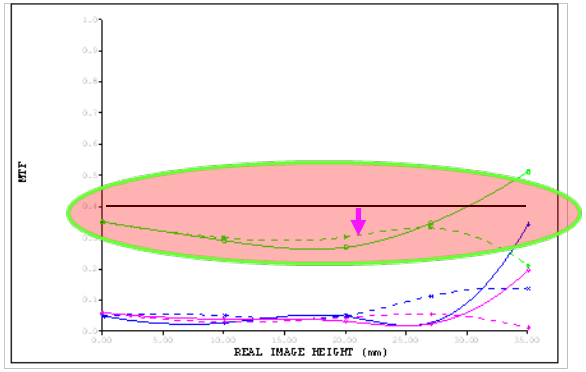
Nyquist 70LP/mm

Nyquist x 2 140LP/mm

Design Criteria fulfilled for RMK-D lens over a very large pressure range. Visibility remains unchanged.

Photographic SLR lens




Nyquist / 2 35LP/mm

Nyquist 70LP/mm

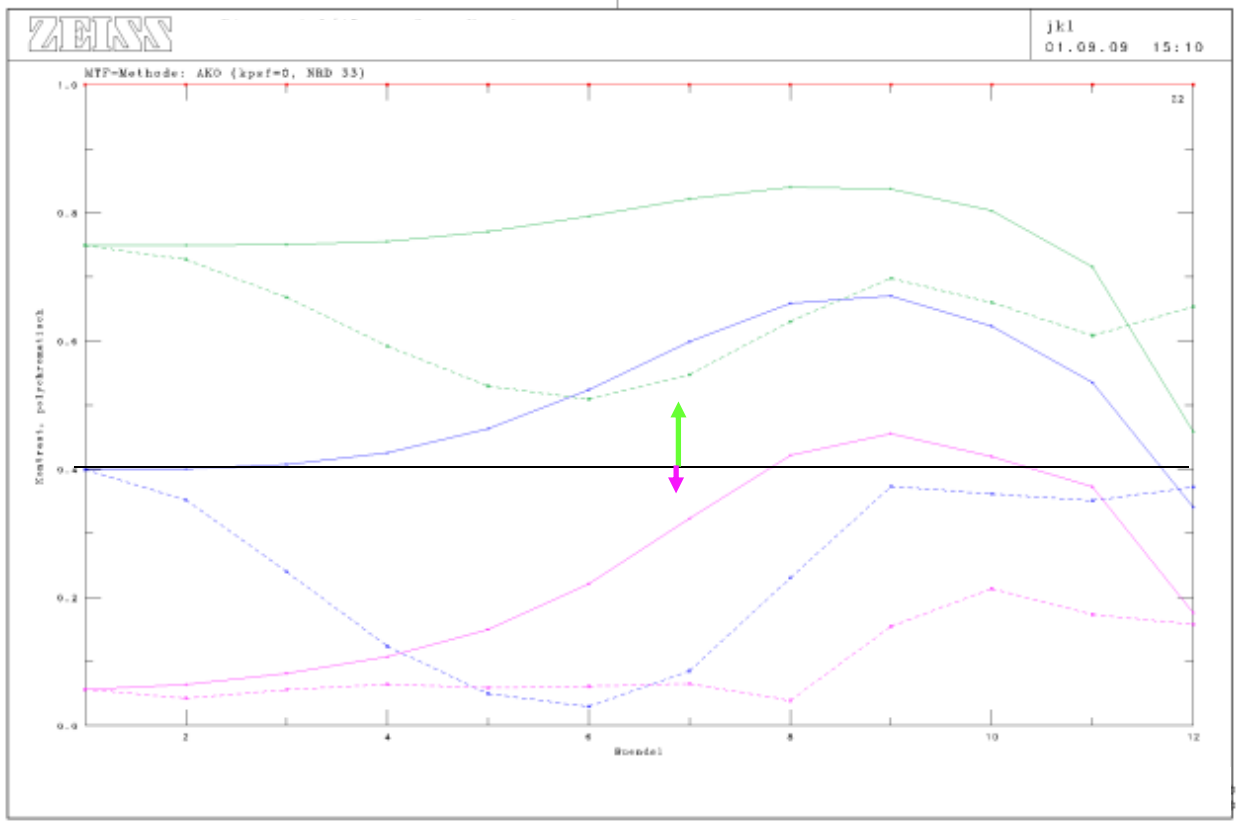
Nyquist x 2 140LP/mm

Visibility criteria not fulfilled within entire image field !
Visibility changes significantly with change in pressure !

**Research & Technology Division**
**Environmental Effects on Image Quality - Temperature**

Modulation Transfer Function (MTF) evaluated for 40°C Temperature change

RMK-D Lens




Nyquist / 2
35LP/mm

Nyquist
70LP/mm

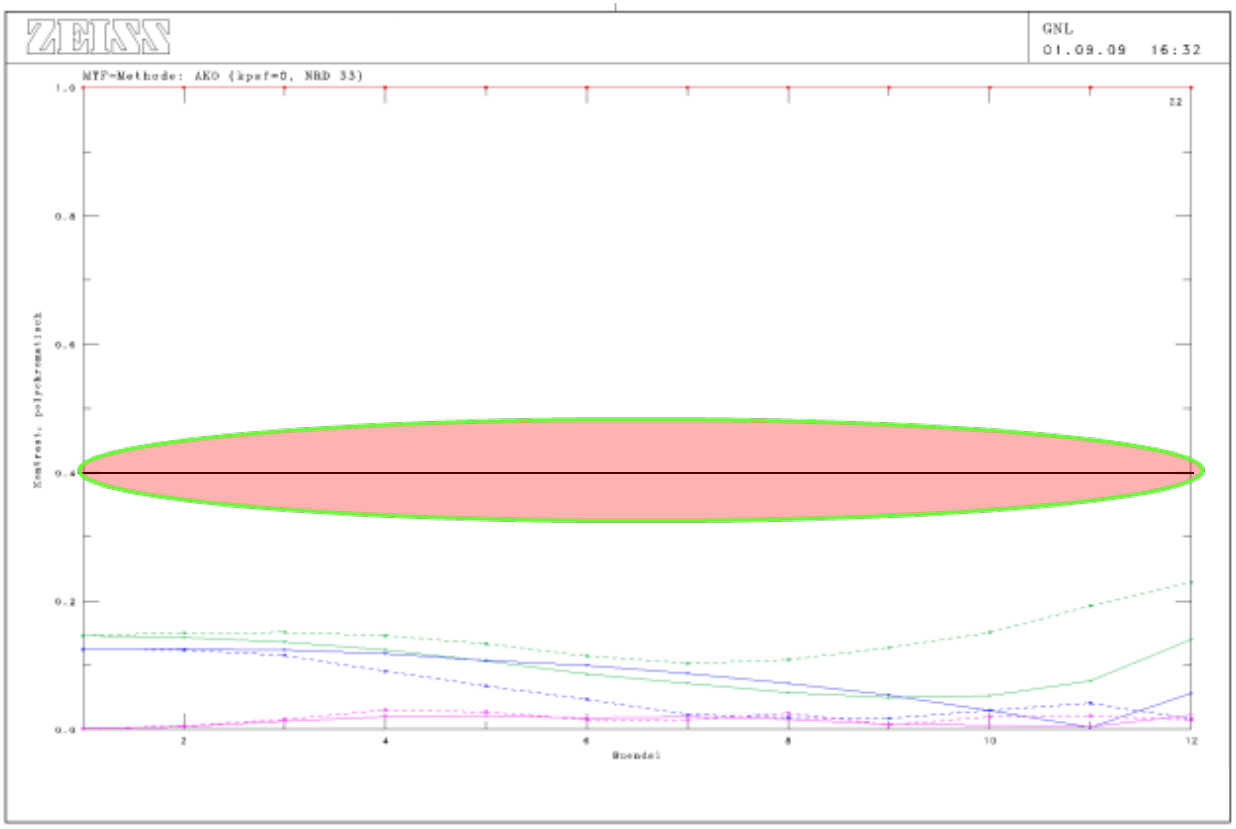
Nyquist x 2
140LP/mm

Design criteria fulfilled for RMK-D lens over a very large temperature range.
Visibility remains unchanged.

**Research & Technology Division**
**Environmental Effects on Image Quality - Temperature**

Modulation Transfer Function (MTF) evaluated for 40°C Temperature change

Photographic SLR lens




Nyquist / 2
35LP/mm

Nyquist
70LP/mm

Nyquist x 2
140LP/mm

Design criteria is not fulfilled within entire image field.
Ability to detect features changes significantly with change in temperature.

Comparison customized design vs. standard photographic lens

+ Full performance with respect to pressure variations

+ Full performance with respect to temperature variations

+ Constant performance with respect to environmental effects

- Photographic lens may **significantly defocus and change image size** due to environmental changes.

- This is **not an issue for photography**, where by refocusing the environmental changes are compensated and magnification stability is not required.

- It may however cause **severe problems for photogrammetric applications**.

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2) Customized Optical Design matching the Sensor Properties
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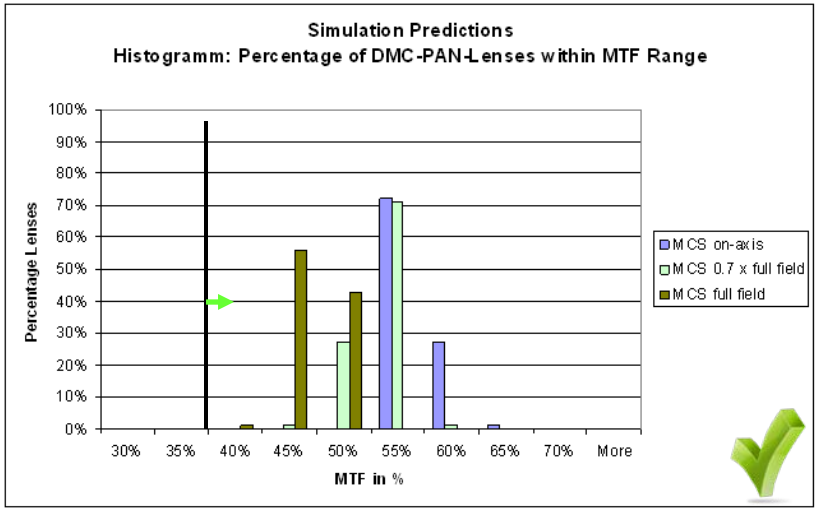
4) As-Build-Performance simulated and measured
5) Conclusion

**Research & Technology Division**
**As-Build-Performance simulated and measured**

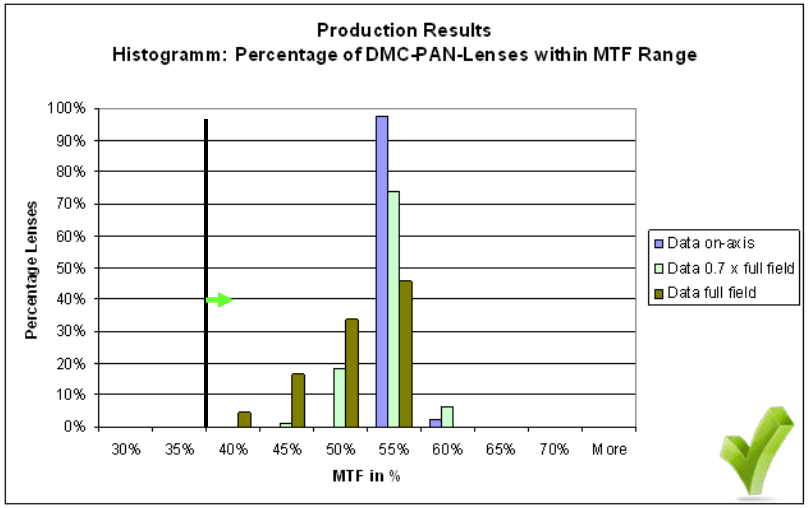
Modulation Transfer Function (MTF) evaluated for 100 DMC PAN Lenses at Nyquist/2.

Simulation Predictions of 100 PAN Lenses




Design criteria fulfilled for DMC-PAN lens in theory over a large number of lenses.

Production Results of 100 PAN Lenses




Design criteria fulfilled for DMC-PAN lens in practice over a large number of lenses.

Full performance over a large number of lenses both in theory and practice.
Agreement between theory and practice => defined production process !

**Research & Technology Division**
**As-Build-Performance simulated and measured**

Customized design

+ Full performance with respect to large number of produced lenses

+ As-build performance very predictable due to defined engineering processes
  => low development risk

+ As-build performance constant over a large number of lenses due to defined production processes
  => low production risk and ramp-up risk

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**Research & Technology Division**
**Conclusion**

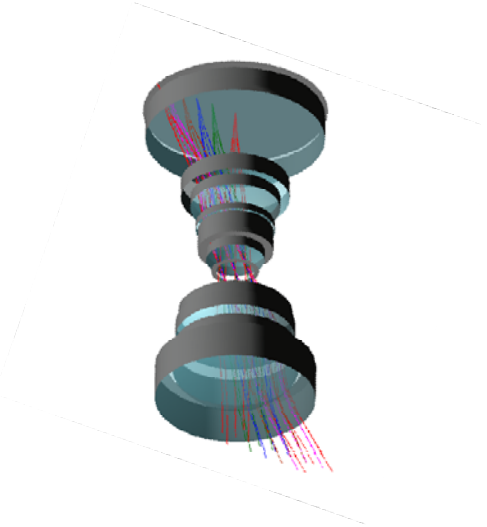
Advantages of customized optical design

+ Performance criteria fulfilled across entire field of view
+ Uniform Performance across the field of view
+ Performance matched to sensor with respect to sensor size, resolution and aliasing

+ Full Performance with respect to large pressure variations
+ Full Performance with respect to large temperature variations
+ Constant Performance with respect to environmental effects

+ Performance criteria fulfilled with respect to large number of produced lenses
+ As-build performance very predictable due to defined engineering processes
  => low development risk
+ As-build performance constant over a large number of lenses due to defined production processes
  => low production and ramp-up risk

There are many advantages using an customized optical design.



It takes a customized mechanical design that supports the superior performance and stability of the optical lens design to achieve superior as-build lens performance.
And it takes the ability to build and adjust according to the requirements of the optical and mechanical design.


We make it visible.