



# Lectures Notes on Optical Design using Zemax OpticStudio

## Thermal Analysis



**Ahmet Bingül**

Gaziantep University  
Department of Optical  
Engineering

**Apr 2024**

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# What is Thermal Analysis?

Optical systems are used in a variety of environments.

Therefore, it is required to model effects of temperature, pressure, etc, in an optical system design.

Modelling of temperature effects on optical system is known as **Thermal Analysis**

It is important to include temperature effects, if temperature change is more than 40 degrees since

- Glass expands / contracts
- Mechanical holders expands / contracts

*In military applications, we may use effect of temperature changes in the range  $\pm 50$  °C.*

# Temperature and Lens Geometry

- Glass expands isotropically (uniformly in all directions).
- That is radii and thickness expand at the same rate.

$T = 20^{\circ}\text{C}$



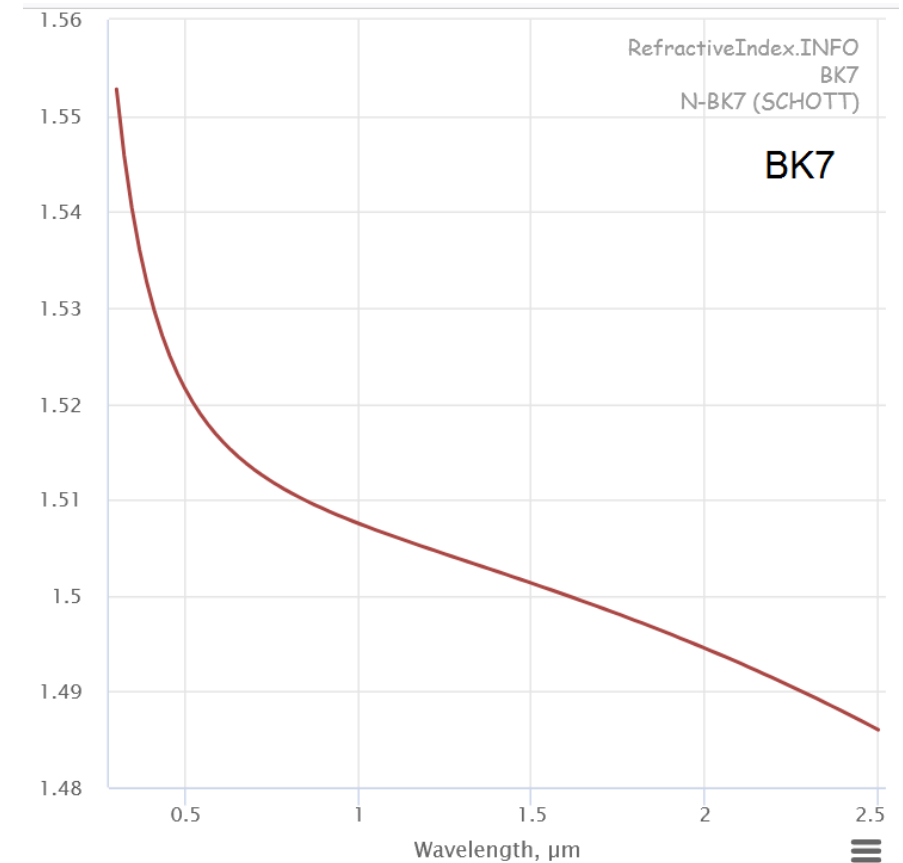
$T = 60^{\circ}\text{C}$



Exaggerated thermal expansion  
of a lens

# Temperature, Pressure and Index of Ref.

- For many optical materials the refractive index decreases as the wavelength increases.in optical region.
- Refractive index
  - of a glass decreases as the temperature of medium increases.
  - of air increases as the pressure of the medium increases.
- Hence, the designer should take these factors into account when making the analysis.



# Temperature and Focal Length of a Lens

Considering the simple case of a single element thin lens, the change in focal length ( $\Delta f$ ) of the lens with temperature is given by:

$$\Delta f = -\gamma f \Delta T = -\left(\frac{dn/dT}{n-1} - \alpha_L\right) f \Delta T$$

$\gamma$  = thermo-optical coefficient of the lens

$dn/dT$  = refractive index change with temperature

$n$  = refractive index of the lens

$\alpha_L$  = thermal expansion coefficient (TCE) of the lens

$f$  = focal length of the lens

$\Delta T$  = temperature change

Thermal effects are especially very important in IR applications. Assume that we have a 75-mm-diameter  $f/1.5$  Germanium lens with a focal length of 112.5 mm

Depth of focus:  $\delta = 0.046$  mm

Change in Focal length:  $\Delta f = 0.599$  mm (for  $\Delta T = 40$  °C)

The difference is very large. Therefore, relatively large temperature change is a very serious problem in thermal infrared systems.

# TCE of Some Materials

<u>Glass</u>	<u>TCE (1/°C)</u>
N-BK7	$7.1 \times 10^{-6}$
N-SF2	$7.1 \times 10^{-6}$
N-SF5	$7.9 \times 10^{-6}$
N-F2	$6.7 \times 10^{-6}$
N-LAF35	$5.3 \times 10^{-6}$
POLYCARB	$60.0 \times 10^{-6}$
Germanium	$5.7 \times 10^{-6}$
ZnSe	$7.2 \times 10^{-6}$

<u>Lens Holder</u>	<u>TCE (1/°C)</u>
Steel	$9 \times 10^{-6}$
Iron	$11 \times 10^{-6}$
Aluminum	$23 \times 10^{-6}$
Brass	$188 \times 10^{-6}$

Materials Catalog

Catalog: SCHOTT.AGF

Glass: N-BAF52, N-BAK1, N-BAK2, N-BAK4, N-BAK4HT, N-BALF4, N-BALF5, N-BASF2, N-BASF64, N-BK10, **N-BK7**, N-BK7HT

Rename: N-BK7

Formula: Sellmeier 1

Status: Preferred

Nd: 1,5168 Vd: 64,167

☐ Ignore Thermal Expansion

☐ Exclude Substitution

☐ Meta Material (Negative Index)

Melt Freq: ? Comment: step 0.5 available

Rel Cost: 1 CR: 1 FR: 0 SR: 1 AR: 2.3 PR: 2.3

K1: 1.03961212E+000 D0: 1.8600E-006

L1: 6.00069867E-003 D1: 1.3100E-008

K2: 2.31792344E-001 D2: -1.3700E-011

L2: 2.00179144E-002 E0: 4.3400E-007

K3: 1.01046945E+000 E1: 6.2700E-010

L3: 1.03560653E+002 Ltk: 1.7000E-001

TCE: 7.1

Temp: 20

p: 2.51

dPgF: -0.0009

Minimum Wavelength: 0.30000000

Maximum Wavelength: 2.50000000

Save Catalog Insert Glass Sort By -> Name: [v]

Save Catalog As Cut Glass Glass Report Catalog Report

Reload Catalog Copy Glass Transmission Compute Nd/Vd

Exit Paste Glass Fit Index Data Fit Melt Data

Material	Refractive Index at 4 $\mu\text{m}$	Refractive Index at 10 $\mu\text{m}$	$dn/dt/^{\circ}\text{C}$	Comments
Germanium	4.0243	4.0032	0.000396	Expensive, large $dn/dt$
Silicon	3.4255	3.4179*	0.000150	Large $dn/dt$
Zinc sulfide, CVD	2.2520	2.2005	0.0000433	
Zinc selenide, CVD	2.4331	2.4065	0.000060	Expensive, very low absorption
AMTIR I (Ge/As/SE33/12/55)	2.5141	2.4976	0.000072	
Magnesium fluoride	1.3526	†	0.000020	Low cost, no ctg required
Sapphire	1.6753	†	0.000010	Very hard, low emissivity at high temperature

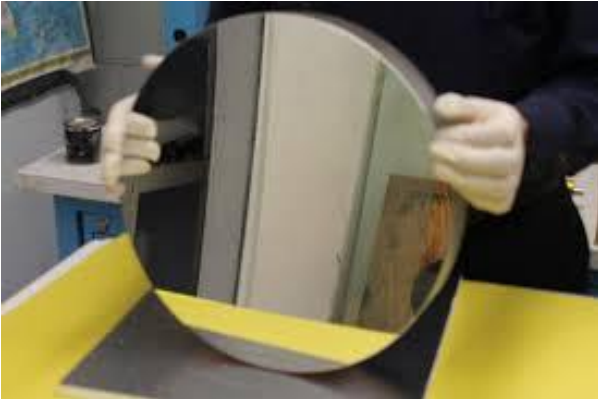


# Zerodur Glass

Zerodur is extremely low expansion glass ceramic from Schott Company. It is used in high-tech applications:

- IC (Integrated Circuit)
- FPD (Flat Panel Display)
- Lithography
- High-precision metrology
- Astronomy (as mirror material)

CTE Grades	CTE (0 °C; 50 °C)*	<i>CTE is TCE in Zemax</i>
ZERODUR® Expansion Class 2	$0 \pm 0.100 \cdot 10^{-6}/K$	
ZERODUR® Expansion Class 1	$0 \pm 0.050 \cdot 10^{-6}/K$	
ZERODUR® Expansion Class 0	$0 \pm 0.020 \cdot 10^{-6}/K$	
ZERODUR® Expansion Class 0 <b>SPECIAL</b>	$0 \pm 0.010 \cdot 10^{-6}/K$	
ZERODUR® Expansion Class 0 <b>EXTREME</b>	$0 \pm 0.007 \cdot 10^{-6}/K$	
ZERODUR® <b>TAILORED</b>	<b>TAILORED</b> $\pm 0.020 \cdot 10^{-6}/K$ ( $\pm 0.010 \cdot 10^{-6}/K$ upon request) Optimized for application temperature profile	



# Athermalization

ChatGPT says:

Athermalization is the process of designing a system or device in such a way that it remains insensitive to changes in temperature.

This can be achieved by various means, such as

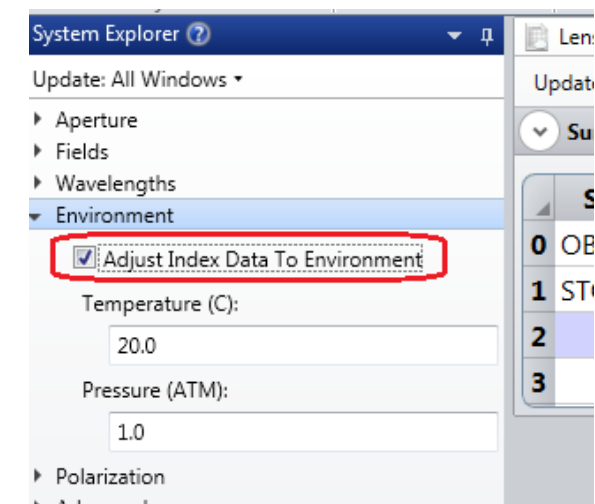
- using materials with low thermal expansion coefficients,
- incorporating compensating elements in the design, or
- using active control systems to regulate the temperature.

Athermalization is particularly important in precision instruments, such as **optical systems** and **electronic circuits**, where changes in temperature can cause drift or changes in performance. By designing these systems to be athermal, their performance can be maintained over a wide temperature range.

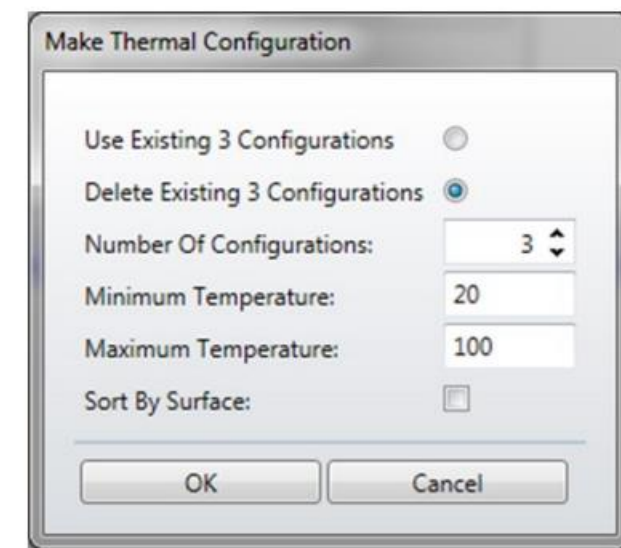
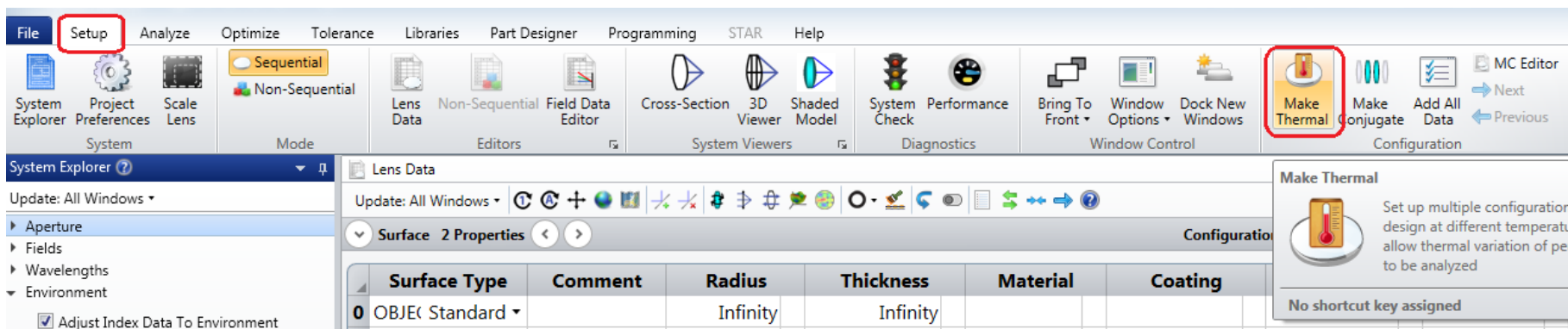
*It is clear that, in design process, the optical system must be optimized to operate at different temperatures.*

# Thermal Analysis in Zemax

Zemax OpticStudio has thermal modeling capability. Before starting thermal analysis, you need to check “Adjust Index Data To Environment” option in System Explorer window.



In Zemax, **Make Thermal** Tool provides modelling thermal effects via MCE



- All parameters that are affected by temperature have to be listed in the Multiple Configuration Editor (MCE).
- Thermal pickups are used for the parameters in the MCE so that those values are automatically computed by Zemax.
- **Make Thermal** tool provides convenient way to insert all operands in the MCE with thermal pickups.

# Example1: Single Lens

Consider the following lens:

Glass: BK7  
Object: at infinity  
 $R_1$ : +250 mm  
 $R_2$ : -300 mm  
ct: 6 mm  
ENPD: 20 mm  
TCE:  $7.1\text{e-}6 / ^\circ\text{C}$   
Wavelength: d-line

Investigate the temperature effects on the spot diagram and EFFL.

Use 4 different temperature configurations and let

$$T_{\min} = -20 ^\circ\text{C}$$

$$T_{\max} = +60 ^\circ\text{C}$$

# Example1: LDE

Initial LDE before Thermal Analysis:

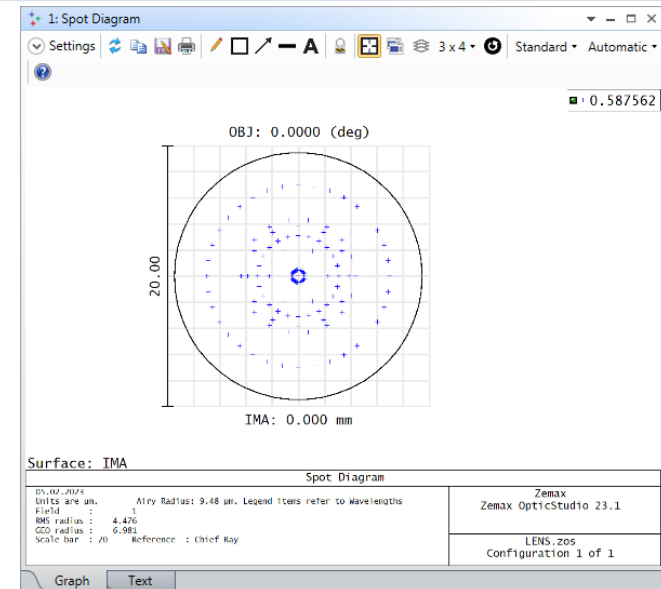
Lens Data												
Update: All Windows												
Surface 4 Properties Configuration 1/1												
	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6	
0	OBJECT Standard		Infinity	Infinity			0.000	0.000	0.000	0.0...	0.000	
1	STOP Standard		Infinity	0.000			10.000 U	0.000	10.000	0.0...	0.000	
2	(aper) Standard		250.000	6.000	BK7		11.000 U	0.000	11.000	0.0...	-	
3	(aper) Standard		-300.000	262.311			11.000 U	0.000	11.000	0.0...	0.000	
4	IMAGE Standard		Infinity	-			6.981E-03	0.000	6.981E-03	0.0...	0.000	

After **Quick Focus** we have

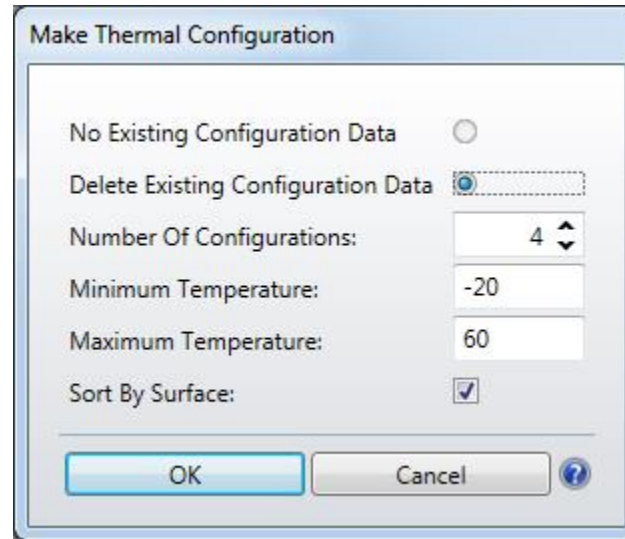
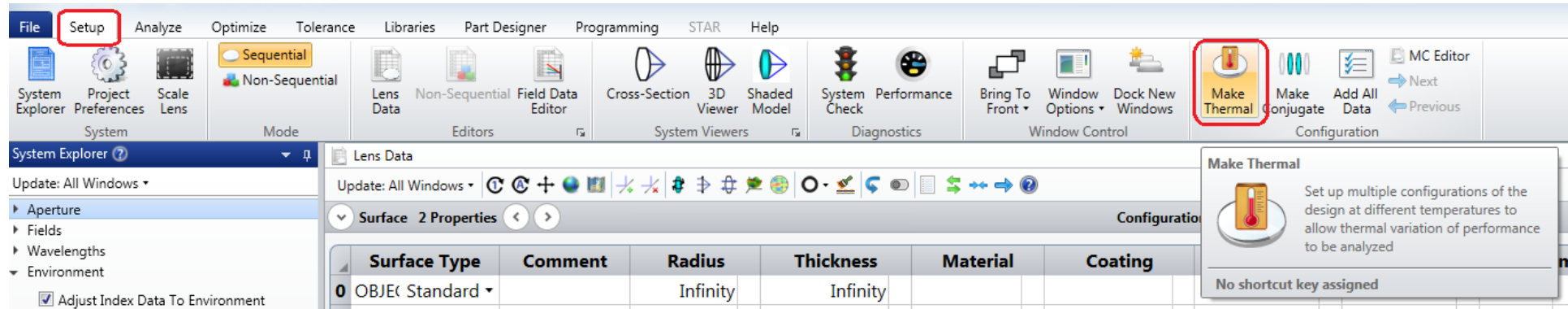
EFFL = 264.8459 mm

RMS Spot Radius = 4.76  $\mu\text{m}$

Airy Disk Radius = 9.48  $\mu\text{m}$



# Example1: Make Thermal



# Example1: MCE Result of Analysis

TEMP: Temperature

PRES: Pressure

THIC: Thickness

CRVT: Curvature

GLSS: Glass

SDIA: SemiDiameter

CHZN: ChipZone

MCSD: Mech. SemiDiameter

<u>T</u>	<u>EFFL</u>	<u>SPOT</u>
-20.0	264.83	4.69
6.6	264.84	4.54
20.0	264.84	4.76
33.3	264.85	4.42
60.0	264.86	4.33

Multi-Configuration Editor													
Update: All Windows													
Operand 14 Properties Configuration 1/5													
	Active : 1/5	Config 1*	Config 2	Config 3	Config 4	Config 5							
1	TEMP -	20.000	-20.000	6.667	33.333	60.000							
2	PRES -	1.000	1.000	1.000	1.000	1.000							
3	THIC 1	0.000	-6.885E-05 T	-2.294E-05 T	2.294E-05 T	6.881E-05 T							
4	CRVT 2	4.000E-03	4.001E-03 T	4.000E-03 T	4.000E-03 T	3.999E-03 T							
5	THIC 2	6.000	5.998 T	5.999 T	6.001 T	6.002 T							
6	GLSS 2	BK7	BK7 P	BK7 P	BK7 P	BK7 P							
7	SDIA 2	11.000	10.997 T	10.999 T	11.001 T	11.003 T							
8	CHZN 2	0.000	0.000 T	0.000 T	0.000 T	0.000 T							
9	MCSD 2	11.000	10.997 T	10.999 T	11.001 T	11.003 T							
10	CRVT 3	-3.333E-03	-3.334E-03 T	-3.334E-03 T	-3.333E-03 T	-3.332E-03 T							
11	THIC 3	262.311	262.311 T	262.311 T	262.311 T	262.311 T							
12	SDIA 3	11.000	10.997 T	10.999 T	11.001 T	11.003 T							
13	CHZN 3	0.000	0.000 T	0.000 T	0.000 T	0.000 T							
14	MCSD 3	11.000	10.997 T	10.999 T	11.001 T	11.003 T							



## Example2: Thermal Analysis of a Mirror

Consider a concave mirror made from aluminum.

$$|R| = 500 \text{ mm}$$

$$\text{ENPD} = 100 \text{ mm}$$

$$\text{TCE} = 23\text{e-}6 / ^\circ\text{C}$$

$$\text{Conic} = -1 \text{ (parabolic mirror)}$$

Investigate the temperature effects on radius and semi-diameter,  
at  $T = 20 ^\circ\text{C}$  and at  $T = +60 ^\circ\text{C}$ .

We have two configurations:

The 'Lens Data' window displays two configurations. Configuration 1/1 shows a table with 8 rows and 8 columns. Configuration 2/2 shows a table with 4 rows and 8 columns. Red boxes highlight the configuration navigation buttons and the TCE x 1E-6 column.

	Surface Type	Comme	Radius	Thickness	Material	TCE x 1E-6	Conic
0	OBJECT	Standard	Infinity	Infinity		0.000	0.000
1	STOP	Standard	Infinity	300.000		0.000	0.000
2		Standard	-500.000	-250.000	MIRROR	23.000	-1.000
3	IMAGE	Standard	Infinity	-		0.000	0.000

	Surface Type	Comme	Radius	Thickness	Material	TCE x 1E-6	Conic
0	OBJECT	Standard	Infinity	Infinity		0.000	0.000
1	STOP	Standard	Infinity	299.998 P		0.000	0.000
2	(aper)	Standard	-500.460 P	-250.230 P	MIRROR	23.000	-1.000
3	IMAGE	Standard	Infinity	-		0.000	0.000

The 'Multi-Configuration Editor' window displays a table with 8 rows and 3 columns. The table shows the active configuration and the values for Config 1\* and Config 2.

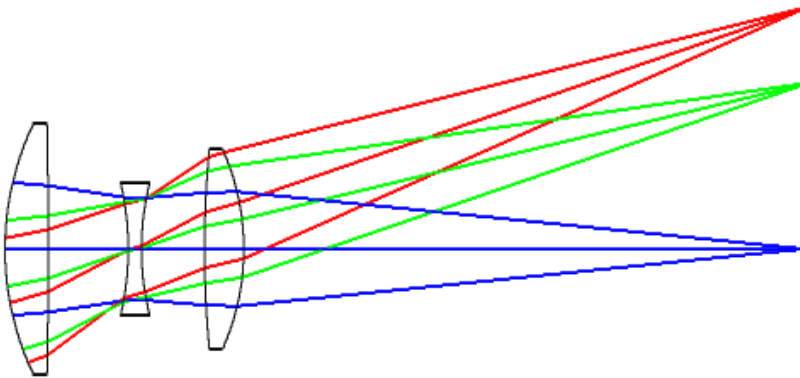
	Active : 1/2	Config 1*	Config 2
1	TEMP	-	20.000
2	PRES	-	1.000
3	THIC	1	300.000
4	CRVT	2	-2.000E-03
5	THIC	2	-250.000
6	SDIA	2	50.000
7	CHZN	2	0.000
8	MCSD	2	50.000

# Example3: Thermal Analysis of a CookeTriplet

In this example, we will investigate the Cooke Triplet at:

<zemax>\Samples\Sequential\Objectives\Cooke 40 degree field.zos

Lens Data X												
Update: All Windows												
Surface 7 Properties												
Configuration 1/1												
	Surface Type	Com	Radius	Thickness	Material	Coating	Clear Semi-D	Chip Zone	Mech Semi-E	Conic	TCE x 1E-6	
0	OBJECT	Standard	Infinity	Infinity			Infinity	0.000	Infinity	0.000	0.000	
1	(aper)	Standard	22.014 V	3.259 V	SK16 S	AR	9.500 U	0.000	9.500	0.000	-	
2	(aper)	Standard	-435.760 V	6.008 V		AR	9.500 U	0.000	9.500	0.000	23.600	
3	(aper)	Standard	-22.213 V	1.000 V	F2 S	AR	5.000 U	0.000	5.000	0.000	-	
4	STOP (aper)	Standard	20.292 V	4.750 V		AR	5.000 U	0.000	5.000	0.000	23.600	
5	(aper)	Standard	79.684 V	2.952 V	SK16 S	AR	7.500 U	0.000	7.500	0.000	-	
6	(aper)	Standard	-18.395 V	42.208 V		AR	7.500 U	0.000	7.500	0.000	23.600	
7	IMAGE	Standard	Infinity	-			18.173	0.000	18.173	0.000	0.000	



Lens holder: Aluminum

EFFL = 50 mm

F/# = 5

FOV = 40°

$\lambda = [0.48, 0.55, 0.65] \text{ nm}$

$$T = \pm 50^{\circ}\text{C}$$

**Make Thermal Configuration**

No Existing Configuration Data ☐


Delete Existing Configuration Data ☒

Number Of Configurations:

Minimum Temperature:

Maximum Temperature:

Sort By Surface: ☒



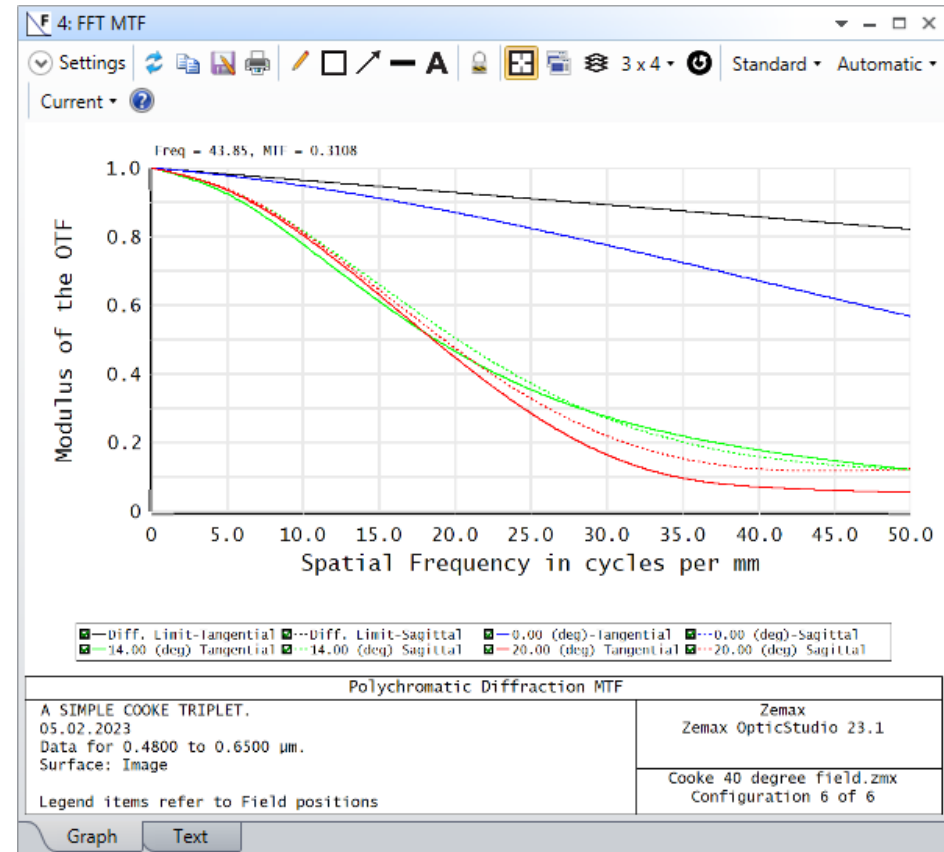
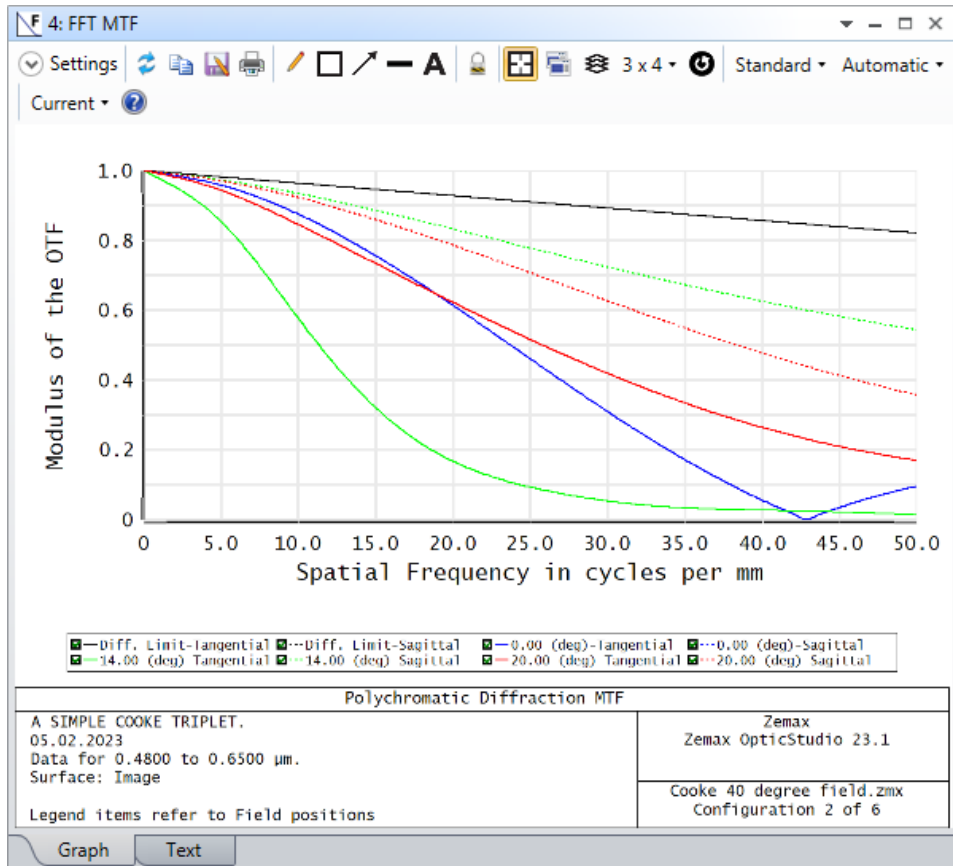
Multi-Configuration Editor

Update: All Windows

Operand 20 Properties Configuration 5/6

	Active : 5/6	Config 1	Config 2	Config 3	Config 4	Config 5*	Config 6
1	TEMP -	20.000	-50.000	-25.000	0.000	25.000	50.000
2	PRES -	1.000	1.000	1.000	1.000	1.000	1.000
3	CRVT 1	0.045	0.045 T	0.045 T	0.045 T	0.045 T	0.045 T
4	THIC 1	3.259	3.258 T	3.258 T	3.259 T	3.259 T	3.260 T
5	GLSS 1	SK16	SK16 P	SK16 P	SK16 P	SK16 P	SK16 P
6	SDIA 1	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T
7	CHZN 1	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
8	MCSD 1	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T
9	CRVT 2	-2.295E-03	-2.296E-03 T	-2.295E-03 T	-2.295E-03 T	-2.295E-03 T	-2.294E-03 T
10	THIC 2	6.008	5.997 T	6.001 T	6.005 T	6.008 T	6.012 T
11	SDIA 2	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T
12	CHZN 2	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
13	MCSD 2	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T

Look into MTF, OPD, RMS vs Field, RMS vs Wavelength, Ray Fan plots.  
You will see effects temperature on the design clearly.



# Example3: Athermalization

To Make system athermal,

1. Setup all CRVT ve GLSS operand as variable in Config 1.
2. For all configurations, at surface 6, all THIC operands must be variable. This is required to get minimum spot radius for all configurations.

	Active : 1/6	Config 1*	Config 2	Config 3	Config 4	Config 5	Config 6
1	TEMP ▾ -	20.000	-50.000	-25.000	0.000	25.000	50.000
2	PRES ▾ -	1.000	1.000	1.000	1.000	1.000	1.000
3	CRVT ▾ 1	0.045 V	0.045 T	0.045 T	0.045 T	0.045 T	0.045 T
4	THIC ▾ 1	3.259	3.258 T	3.258 T	3.259 T	3.259 T	3.260 T
5	GLSS ▾ 1	SK16	SK16 P	SK16 P	SK16 P	SK16 P	SK16 P
6	SDIA ▾ 1	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T
7	CHZN ▾ 1	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
8	MCSD ▾ 1	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T
9	CRVT ▾ 2	-2.295E-03 V	-2.296E-03 T	-2.295E-03 T	-2.295E-03 T	-2.295E-03 T	-2.294E-03 T
10	THIC ▾ 2	6.008	5.997 T	6.001 T	6.005 T	6.008 T	6.012 T
11	SDIA ▾ 2	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T
12	CHZN ▾ 2	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
13	MCSD ▾ 2	9.500	9.496 T	9.497 T	9.499 T	9.500 T	9.502 T
14	CRVT ▾ 3	-0.045 V	-0.045 T	-0.045 T	-0.045 T	-0.045 T	-0.045 T
15	THIC ▾ 3	1.000	0.999 T	1.000 T	1.000 T	1.000 T	1.000 T
16	GLSS ▾ 3	F2	F2 P	F2 P	F2 P	F2 P	F2 P
17	SDIA ▾ 3	5.000	4.997 T	4.998 T	4.999 T	5.000 T	5.001 T
18	CHZN ▾ 3	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
19	MCSD ▾ 3	5.000	4.997 T	4.998 T	4.999 T	5.000 T	5.001 T
20	CRVT ▾ 4	0.049 V	0.049 T	0.049 T	0.049 T	0.049 T	0.049 T
21	THIC ▾ 4	4.750	4.742 T	4.745 T	4.748 T	4.751 T	4.754 T
22	SDIA ▾ 4	5.000	4.997 T	4.998 T	4.999 T	5.000 T	5.001 T
23	CHZN ▾ 4	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
24	MCSD ▾ 4	5.000	4.997 T	4.998 T	4.999 T	5.000 T	5.001 T
25	CRVT ▾ 5	0.013 V	0.013 T	0.013 T	0.013 T	0.013 T	0.013 T
26	THIC ▾ 5	2.952	2.951 T	2.951 T	2.952 T	2.952 T	2.953 T
27	GLSS ▾ 5	SK16	SK16 P	SK16 P	SK16 P	SK16 P	SK16 P
28	SDIA ▾ 5	7.500	7.497 T	7.498 T	7.499 T	7.500 T	7.501 T
29	CHZN ▾ 5	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
30	MCSD ▾ 5	7.500	7.497 T	7.498 T	7.499 T	7.500 T	7.501 T
31	CRVT ▾ 6	-0.054 V	-0.054 T	-0.054 T	-0.054 T	-0.054 T	-0.054 T
32	THIC ▾ 6	42.208 V	42.140 V	42.164 V	42.188 V	42.213 V	42.237 V
33	SDIA ▾ 6	7.500	7.497 T	7.498 T	7.499 T	7.500 T	7.501 T
34	CHZN ▾ 6	0.000	0.000 T	0.000 T	0.000 T	0.000 T	0.000 T
35	MCSD ▾ 6	7.500	7.497 T	7.498 T	7.499 T	7.500 T	7.501 T

## Example3: MFE

Select Spot for Image Quality and press **OK**.

The screenshot shows the 'Merit Function Editor' window. The 'Optimization Wizard' tab is active, showing 'Current Operand (2)'. The 'Optimization Function' section has the following settings: Image Quality: Spot, Spatial Frequency: 30, X Weight: 1, Y Weight: 1, Type: RMS, Reference: Centroid, Max Distortion (%): 1 (unchecked), and Ignore Lateral Color (unchecked). The 'Optimization Goal' section has: Best Nominal Performance (selected), Improve Manufacturing Yield (unchecked), and Weight: 1. The 'Pupil Integration' section has: Gaussian Quadrature (selected), Rectangular Array (unchecked), Rings: 3, Arms: 6, and Obscuration: 0. The 'Start At' field is set to 1, and the 'Overall Weight' is set to 1. At the bottom are buttons for OK, Apply, and Close.

Merit Function Editor

Wizards and Operands

Optimization Wizard

Current Operand (2)

Optimization Function

Image Quality: Spot

Spatial Frequency: 30

X Weight: 1

Y Weight: 1

Type: RMS

Reference: Centroid

☐ Max Distortion (%): 1

☐ Ignore Lateral Color

Optimization Goal

☒ Best Nominal Performance

☐ Improve Manufacturing Yield

Weight: 1

Pupil Integration

☒ Gaussian Quadrature

☐ Rectangular Array

Rings: 3

Arms: 6

Obscuration: 0

Start At: 1

Overall Weight: 1

OK Apply Close

Set EFFL = 50 mm.

Merit Function Editor

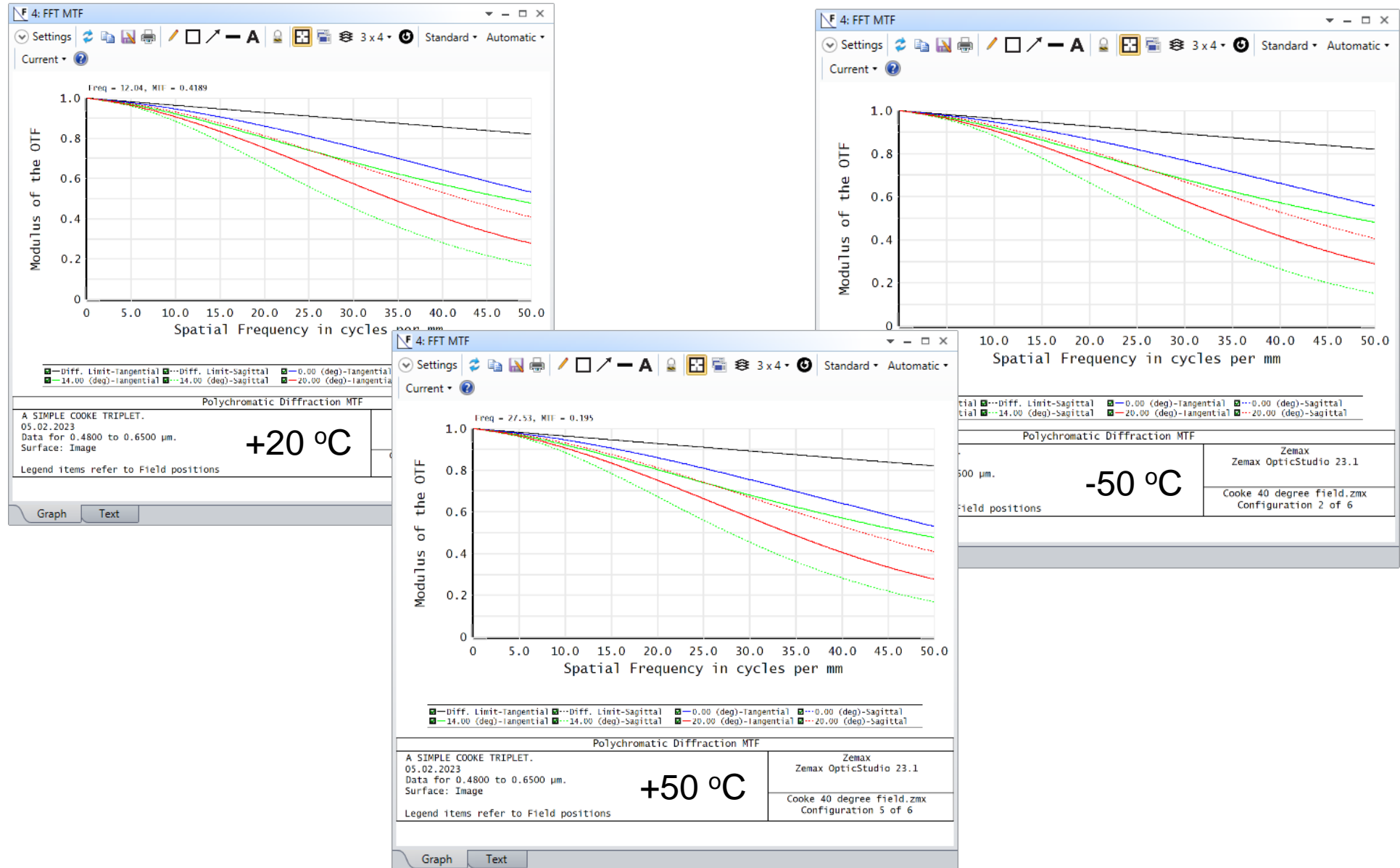
Wizards and Operands      Merit Function: 0.00838464725379272

	Type	Wave							Target	Weight	Value	% Contrib
1	CONF ▾	1										
2	EFFL ▾	2						50.000	1.000	0.000	0.000	
3	DMFS ▾											
4	BLNK ▾	Sequential merit function: RMS spot x+y centroid X Wgt = 1.0000 Y Wgt = 1.0000 GQ 3 rings 6 a										
5	CONF ▾	1										
6	BLNK ▾	No air or glass constraints.										
7	BLNK ▾	Operands for field 1.										
8	TRCX ▾	1	0.000	0.000	0.336	0.000		0.000	0.078	5.434E-03	0.100	
9	TRCY ▾	1	0.000	0.000	0.336	0.000		0.000	0.078	0.000	0.000	
10	TRCX ▾	1	0.000	0.000	0.707	0.000		0.000	0.124	4.222E-03	0.096	
11	TRCY ▾	1	0.000	0.000	0.707	0.000		0.000	0.124	0.000	0.000	
12	TRCX ▾	1	0.000	0.000	0.942	0.000		0.000	0.078	-8.163E-04	2.250E-03	
13	TRCY ▾	1	0.000	0.000	0.942	0.000		0.000	0.078	0.000	0.000	
14	TRCX ▾	2	0.000	0.000	0.336	0.000		0.000	0.097	5.685E-03	0.136	

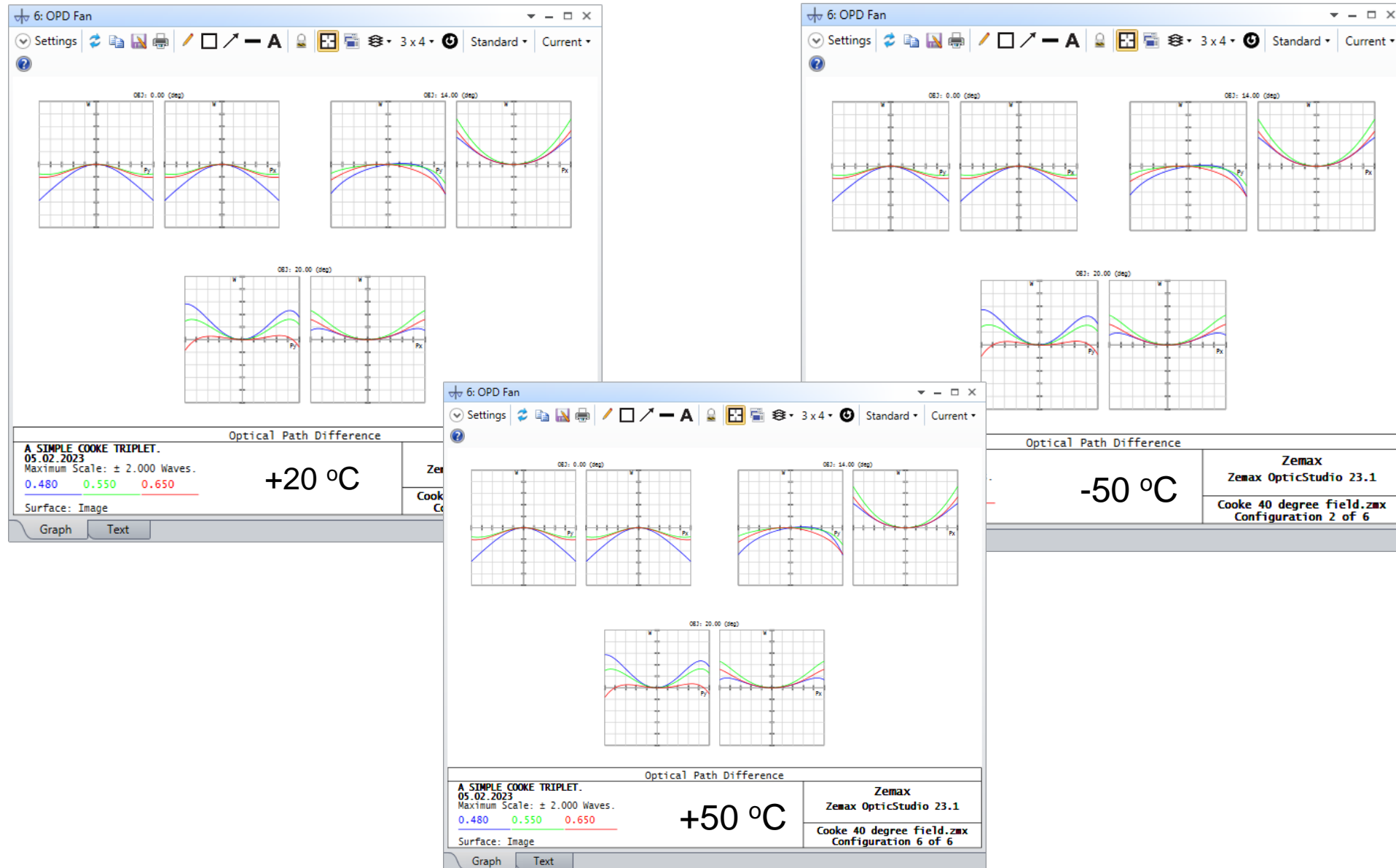
In **Optimize** Tab, click on **Hammer Current** and wait a few minutes.  
You will see the decrease of thermal effects on the system.



# Example3: Athermalization (MTF plot)



# Example3: Athermalization (OPD)



## Example3: Athermalization (Result)

<u>T</u>	<u>EFFL (mm)</u>	<u>TOTR (mm)</u>
-50	50.06	60.64
-25	50.04	60.61
0	50.02	60.59
<b>+20</b>	<b>50.00</b>	<b>60.58</b>
+25	50.00	60.57
+50	49.97	60.55
	$\Delta f = 90 \text{ } \mu\text{m}$	$\Delta L = 90 \text{ } \mu\text{m}$

At 20 °C, depth of focus is  $\delta = \pm 27.5 \text{ } \mu\text{m}$ .

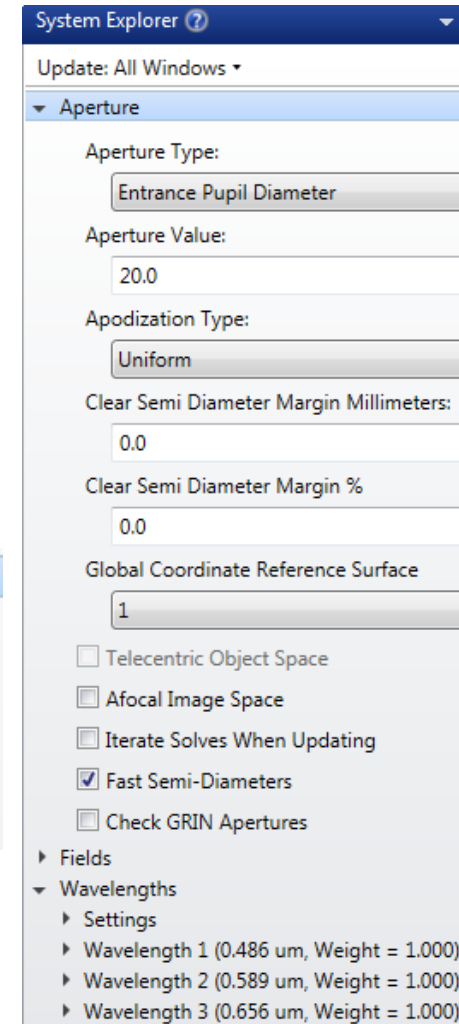
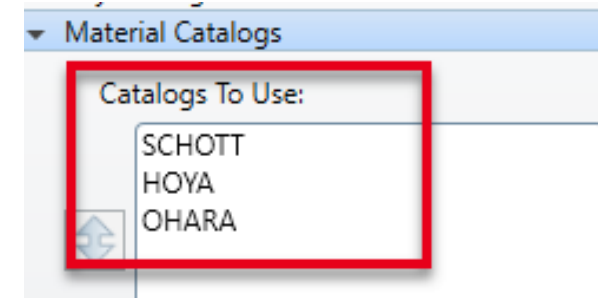
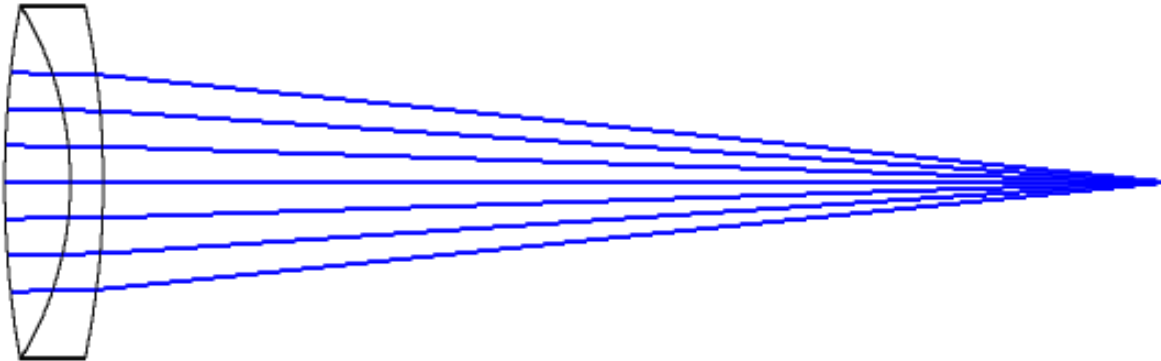
Since  $\Delta L/2 > \delta$ , we may need manual or auto focus system.

*Remember, one way to make a system athermal is to translate (move) lens elements by a greater or lesser amount depending on the magnification.*

# Example4: Athermal Doublet Design

In this example we will design an athermal doublet whose LDE is as follows at 20 °C.  
We want to design it such that the optical performances are almost the same at 20 °C and 100 °C.

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-D	
0	OI Standard ▾		Infinity	Infinity			0.000	
1	ST Standard ▾		92.847 V	6.000	BK7 S		16.000 U	
2	(a) Standard ▾		-30.716 V	3.000	F2 S		16.000 U	
3	(a) Standard ▾		-78.197 V	97.360 V			16.000 U	
4	IV Standard ▾		Infinity	-			0.010	



Multi-Configuration Editor

Update: All Windows

Operand 13 Properties

	Active : 1/2		Config 1*		Config 2
1	TEMP	-	20.000		100.000
2	PRES	-	1.000		1.000
3	CRVT	1	0.011 V		0.011 T
4	CRVT	2	-0.033 V		-0.033 T
5	CRVT	3	-0.013 V		-0.013 T
6	THIC	1	6.000		6.003 T
7	THIC	2	3.000		3.002 T
8	THIC	3	97.360 V		97.361 T
9	GLSS	1	BK7 S		BK7 P
10	GLSS	2	F2 S		F2 P
11	SDIA	1	16.000		16.009 T
12	SDIA	2	16.000		16.010 T
13	SDIA	3	16.000		16.010 T

Merit Function Editor

Wizards and Operands

Merit Function: 0.0780354698024362

	Type	Cfg#											
1	CONF	1											
2	EFFL		2					100.000	1.000	100.000	1.983E-09		
3	GTCE	1						0.000	0.000	7.100	0.000		
4	GTCE	2						0.000	0.000	8.200	0.000		
5	DIFF	3	4					0.000	0.000	-1.100	0.000		
6	ABSO	5						0.000	0.000	1.100	0.000		
7	OPLT	6						1.000	1.000	1.100	19.825		
8	DMFS												
9	BLNK	Default merit function: RMS wavefront centroid GQ 3 rings 6 arms											
10	CONF	1											

EFFL: Effective Focal Length

GTCE: Glass TCE value

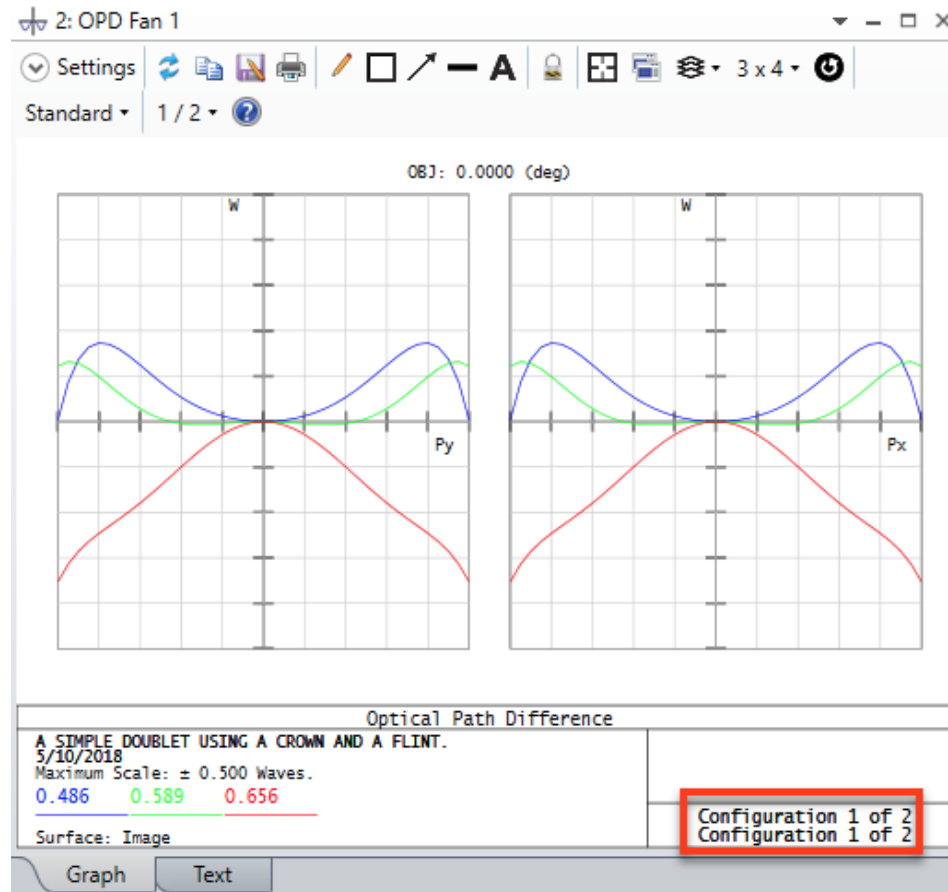
DIFF: Difference between operands

ABSO: Absoute Value

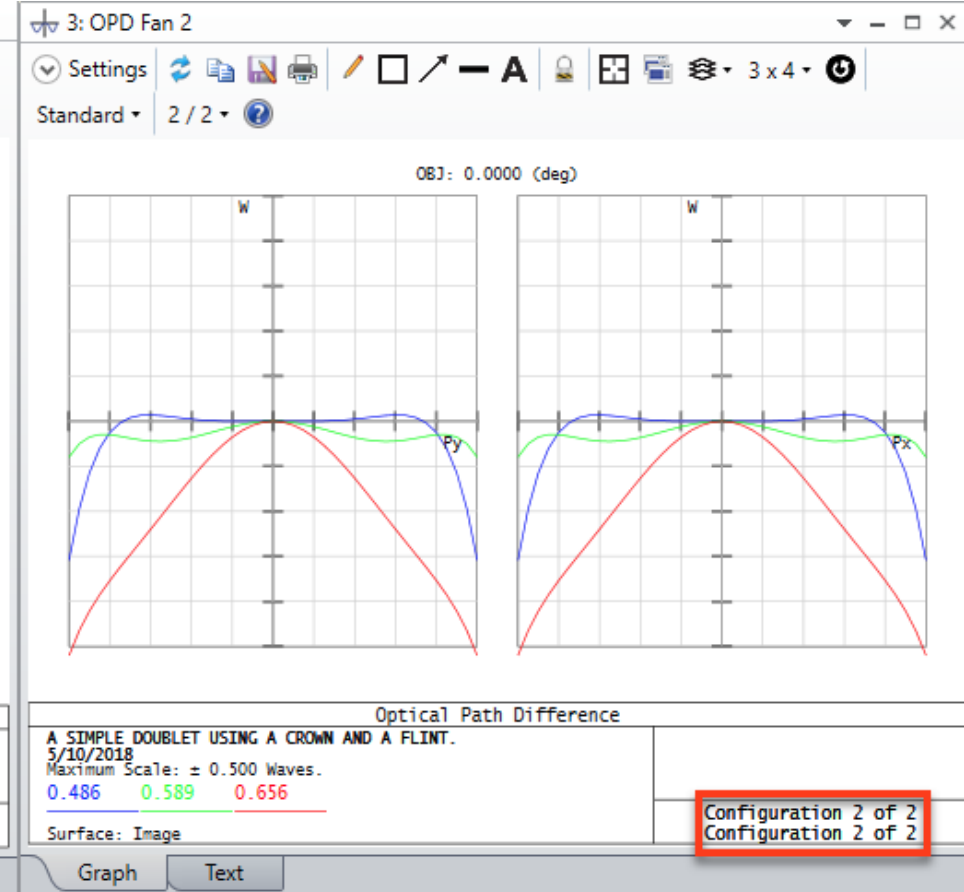
OPLT: Operand Less Than

# Example4: OPD Before Optimization

$T = 20\text{ }^{\circ}\text{C}$

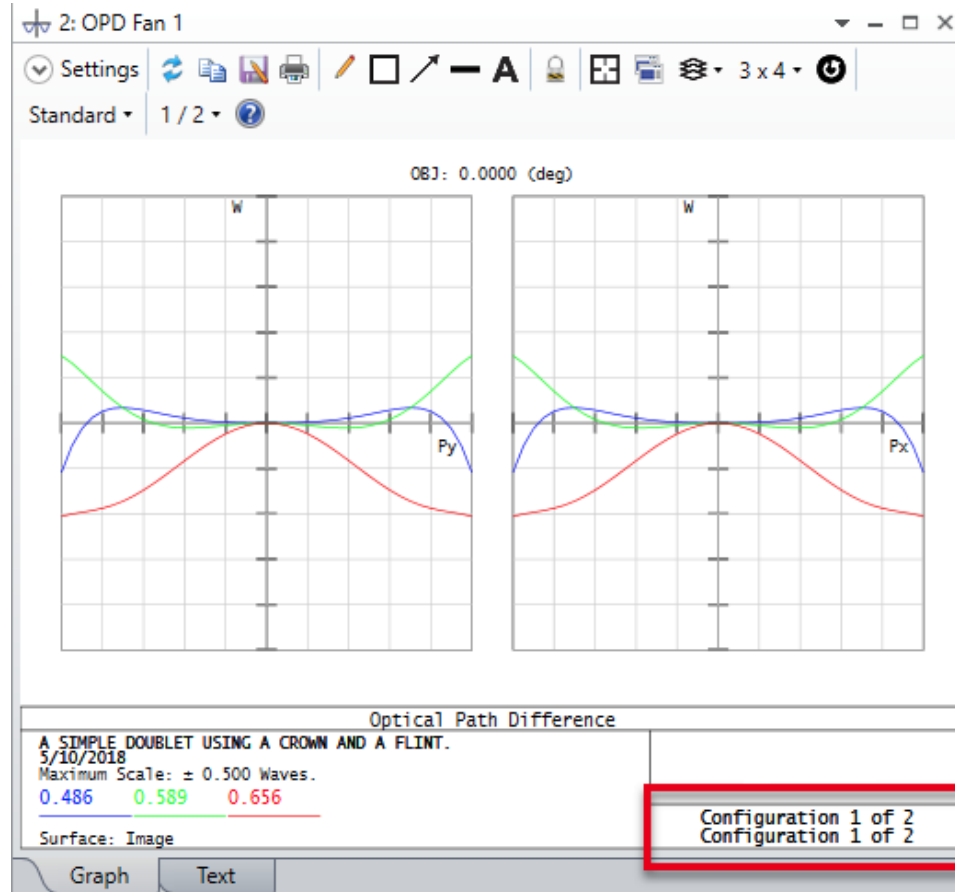


$T = 100\text{ }^{\circ}\text{C}$



# Example4: OPD After Optimization

$T = 20\text{ }^{\circ}\text{C}$



$T=100\text{ }^{\circ}\text{C}$

