IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 17, Issue 2 Ser. 3 (Mar. – Apr. 2025), PP 01-14
www.Iosrjournals.Org

Athermalization And Near Focus Analysis Of The Gun Scope Optical System With An Uncooled LWIR Thermal Imaging Sensor

Faiqah Bint Monir, Kashif Ali Pervaiz
(Kingdom Of Saudi Arabia)

Abstract:
Gun scopes equipped with uncooled thermal imaging sensors operating in the LWIR (Long-Wave Infrared) range of 8–12 µm are advanced optical devices essential for military and law enforcement applications. These forces operate in extreme environments, from freezing mountain ranges to scorching deserts, requiring equipment that performs reliably under all conditions. This paper presents an athermal optical design for a Gun scope optimized for extreme temperatures ranging from -10°C to +60°C. A near-focus analysis is conducted at 10 m for a temperature of 20°C, as well as across the full temperature range. The optical system is built around an uncooled (LWIR) microbolometer sensor with a 640 × 480-pixel focal plane array (FPA) and a 17 µm pixel pitch [1]. Designed using SYNOPSYS™ [2] optical design software, the system features an F-number of 1.5, a 105 mm focal length, and a 7.42° full field of view. It consists of three lenses, including one aspheric element, with a total weight of 210 grams and an optical length of 130 mm, ensuring a compact and lightweight design [1]. Active athermalization is achieved through the controlled movement of a single lens along the optical axis. Performance analysis reveals that the polychromatic Modulation Transfer Function (MTF) at the Nyquist frequency, with a value of 0.446 at on-axis and 0.44 at 0.75 field, decreases to less than 5% at 60°C and to less than 2% at -10°C when utilizing an aluminum housing [3]. For near-focus conditions, the on-axis polychromatic MTF drop at the Nyquist frequency remains below 5% across the entire temperature range. Additional image quality metrics, including Optical Path Difference (OPD) and Strehl ratio, as well as image analysis using extended sources, are also presented. The active athermalization approach is chosen for its cost-effectiveness and simplicity. The lens movement is implemented through a manual thread-based linear focusing mechanism, ensuring a lightweight and efficient solution.

Keywords: *Thermal imaging systems, Gun scope, Uncooled microbolometer sensor, SYNOPSYS^{TM}, Aspheric surface, Nyquist frequency, Polychromatic Modulation Transfer Function (MTF), Diffraction-limited, Chromatic aberration, Optical Path Difference (OPD), Strehl ratio, Athermalization, Active Athermalization, Near focus.*

Date of Submission: 22-03-2025 Date of Acceptance: 02-04-2025

I. Introduction

Gun scopes equipped with uncooled thermal imaging sensors operating in the LWIR (Long-Wave Infrared) range of 8–12 µm represent a major advancement in optical technology, playing a crucial role in military and law enforcement operations. These advanced devices enable personnel to detect heat signatures and maintain visibility in total darkness, as well as through smoke, fog, and other visual obstructions. The uncooled design enhances durability and reliability by eliminating complex cooling systems, which are often vulnerable to failure in harsh environments.

Designed for extreme conditions, these scopes deliver consistent performance in freezing mountain terrains and scorching desert landscapes, ensuring precise target detection and engagement. Their ability to operate reliably under diverse environmental challenges is essential for missions requiring precision, situational awareness, and operational effectiveness. The ruggedness and adaptability of LWIR thermal imaging Gun scopes make them indispensable tools for enhancing mission success and personnel safety in demanding conditions.

Designing optical systems for Gun scopes used by military and law enforcement personnel in extreme temperature environments requires athermalization—a technique that stabilizes optical performance despite temperature fluctuations [4]. When an optical system is exposed to varying temperatures, several factors come into play: lens elements expand or contract, the housing undergoes dimensional changes, and the refractive index of lens materials increases or decreases [5].

Thermal Gun scopes operating in the LWIR spectral band (8–12 µm) rely on infrared materials such as germanium (Ge), zinc selenide (ZnSe), zinc sulfide (ZnS), and chalcogenide glasses. These materials exhibit significant variations in refractive index with temperature changes (dn/dT), causing substantial alterations in optical parameters such as radii and thickness. Additionally, changes in housing dimensions affect the spacing between optical components, leading to a considerable focus shift as a function of temperature [5,6]. To counteract this focus shift effect, athermalization is essential but challenging.

Athermalization strategies are classified into two categories: passive and active. Passive athermalization compensates for thermal focus shift by carefully selecting materials with different thermal expansion and refractive index changes with temperature, dn/dT [7]. However, this approach often requires multiple infrared elements, increasing design complexity and cost.

Active athermalization, on the other hand, compensates for focus shift by mechanically adjusting the focus of the optical system. While shifting the detector assembly is impractical due to electronic connections, and moving the large front element is challenging, the most efficient method is to adjust an internal optical element by a calculated amount [5]. This approach is more cost-effective, as it minimizes the number of expensive IR materials required while still maintaining stable optical performance across a wide temperature range.

In a Gun scope, near-focus capability is essential for military and law enforcement applications, particularly in close-quarter combat, tactical operations, and surveillance. Near focus refers to the shortest distance at which the scope can clearly focus on a target. This feature enhances targeting precision in close-range scenarios, which is critical for mission success and operational safety. Accurate focus at short distances minimizes the risk of misidentification and improves overall efficiency.

Maintaining near-focus capability in extreme environments ensures that the scope remains reliable and accurate despite environmental stressors. Since Gun scope optical systems are primarily designed for long-range viewing, refocusing is necessary for closer targets. This adjustment is achieved by axially shifting a single lens or a group of lenses either toward or away from the sensor. Typically, the same lens used for athermalization is also utilized for near focus, simplifying the optomechanical design and enhancing the efficiency of the refocusing mechanism.

II. Design And Experimental Work

Design Specifications (Technical Parameters):

The Gun scope optical system is designed around an uncooled LWIR microbolometer FPA with a resolution of 640 × 480 pixels and a unit cell size of 17 µm × 17 µm. The image plane measures 10.88 mm × 8.16 mm, with an array aspect ratio of 1.33. The detector includes a 1 mm thick germanium window (filter) that operates within the 8–12 µm spectral range. The Gun scope design achieves diffraction-limited performance under standard conditions (20°C). The design is lightweight, simple, and well-suited for Gun scope application. [1].

The system must function reliably in extreme temperature conditions, ranging from -10°C to +60°C. Additionally, it must maintain a near-focus capability at 10 meters under standard conditions (20°C) and across the full temperature range. The detailed design specifications are provided in Table 1.

Table 1: Design Specifications

Entrance Pupil Diameter (mm)	70
System Focal Length (mm)	105
HFOV×VFOV (deg)	5.94×4.45
Full diagonal FOV (deg)	7.42
System Length (mm)	< 140
F/number	1.5
Detector window thickness (mm)	1
Distance from window to FPA (mm)	0.95
Operating Temperature Range (°C)	-10 to +60
Near Focus (m)	10
Focusing Range (m)	10 to infinity

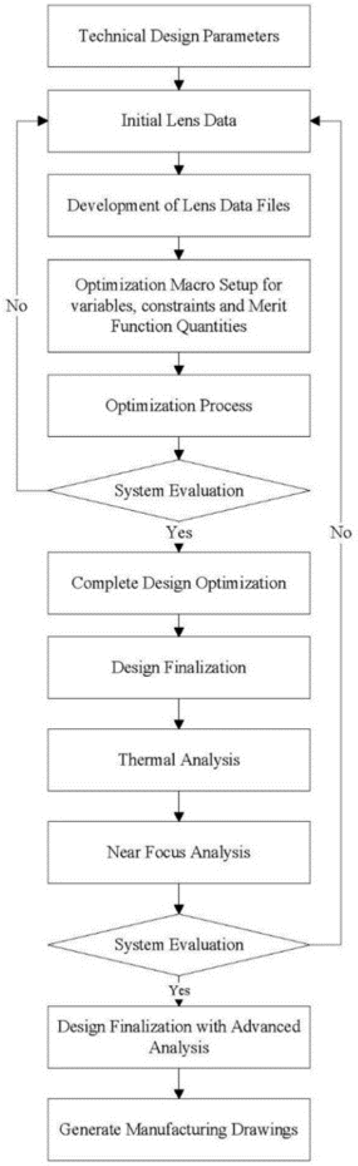

Figure 1: Gun Scope Optical Design Steps

Design Performance Criteria:

The optical design of the Gun scope system meets key performance criteria, ensuring high imaging quality and reliability. The system achieves an MTF greater than 0.424 at the Nyquist frequency, with values of 0.446 for the on-axis field, 0.434 for the 0.75 field, and 0.441 for the full field of view (FOV). The Optical Path Difference (OPD) remains within the Rayleigh criterion of 0.25 waves across the entire FOV [8], while the Strehl ratio exceeds 0.95 [8], confirming that the design is diffraction-limited [1].

The optical system performance under varying temperatures is acceptable, with the drop in polychromatic MTF values at the Nyquist frequency of less than 5% at 60°C and no more than 2% at -10°C when placed in an aluminum housing [2]. Additionally, when the OPD meets Rayleigh criteria for both temperature extremes for the on-axis field, and the Strehl ratio remains at 0.8 across the entire operating range of -10°C to +60°C.

For near-focus performance to be acceptable, the on-axis MTF degradation is limited to less than 5% at 20°C, 60°C, and -10°C, ensuring consistent image quality at close distances.

Design Procedure:

Gun Scope Optical Design Steps for Athermalization and Near Focus:

To develop an optical system for a gun scope that meets the required design specifications and performance criteria, a structured design process is followed [1]. Additional steps are incorporated into this methodology to account for athermalization and near-focus capabilities, as illustrated in Figure 1.

Gun Scope Optical System Modeling and Optimization in SYNOPSYS^{TM}:

This study utilizes SYNOPSYS™ optical design software [2] for in-depth system analysis and optimization. The final design is developed through a structured process, as illustrated in Figure 1. The core design steps, from Defining technical parameters to Finalizing the design, follow the methodology outlined earlier [1], [8]. Additional steps incorporated into the process are detailed below:

Thermal Analysis:

- A custom thermal macro is created to account for variations in the refractive index of lens materials due to temperature changes, incorporating their respective coefficients of thermal expansion.
- Changes in lens curvature and thickness caused by temperature fluctuations are identified, allowing for the expansion and contraction of materials to be taken into account in the analysis.
- The impact of thermal expansion on the housing material is also accounted for in the macro using its coefficient of thermal expansion data.
- After running the thermal macro, the optical system is refocused by adjusting the position of a lens or a group of lenses.
- Using Optical Path Difference (OPD) curves at 20°C as a reference for diffraction-limited performance, incremental adjustments in lens positioning are made to achieve optimal focus.

Near Focus Analysis:

- The object definition in the (RLE.) file is modified from an object at infinity to one at the designated near-focus distance.
- OPD curves from the infinity-focused design serve as a reference for diffraction-limited performance.
- The system is refocused by making small adjustments to the position of a lens or a group of lenses to achieve optimal near-focus performance.

System Evaluation:

- The system's optical performance is verified using the Image Analysis Dialog (MIM) to ensure it meets design criteria and performance requirements for the entire temperature range and near focus distance.

Design Finalization with Advanced Analysis:

- The design is finalized once all technical specifications are met, ensuring optimal performance at 20°C and across the entire operating temperature range, as well as at the specified near focus distance.

Manufacturing Drawings:

- After finalizing the design, detailed manufacturing drawings are generated for production.

Final Design Specifications (Technical Parameters) Achieved:

By following the outlined design steps, the optical specifications for the Gun scope are finalized. The achieved design specifications are summarized in Table 2.

Table 2: Final Design Specifications

	Required Technical specifications	Final Technical Specifications
Entrance Pupil Diameter (mm)	70	70
System Focal Length (mm)	105	105
HFOV×VFOV (deg)1	5.94×4.45	5.94×4.45
Full diagonal FOV (deg)	7.42	7.42
System Length (mm)2	< 140	130
F/number	1.5	1.5
Operating Temperature Range (°C)	-10 to +60	-10 to +60
Near Focus (m)	10	10
Focusing Range (m)	10 to infinity	10 to infinity

Figure 2 illustrates the 2D layout of the gun scope optical design, highlighting the movement of the third lens. The lens shifts to the right when moved closer to the sensor and to the left when positioned further away from the sensor.

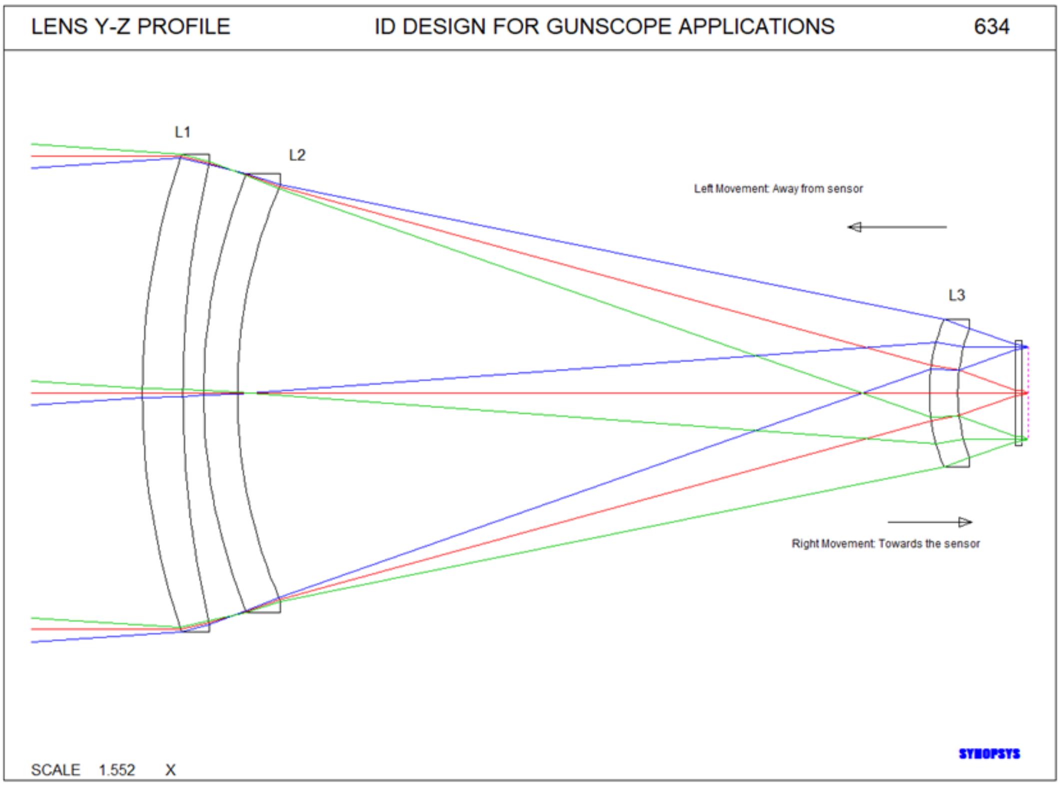

Figure 2: 2D Layout with Third Lens Movement

III. Results And Discussion

Optical Design Details:

The optical system designed for a Gun scope application has been thoroughly analyzed, incorporating an uncooled microbolometer FPA-based sensor operating within the 8–12 µm wavelength range. The system's performance has been evaluated under extreme temperature conditions, ranging from +60 °C to -10 °C, as well as at near-focus distances of 10 m at 20 °C and across the full temperature range of +60 °C to -10 °C.

The optical design demonstrates excellent correction of aberrations, maintaining an MTF drop of less than 5% at the Nyquist frequency of 29.4 lp/mm for both on-axis and 0.75 field points at +60 °C, and less than 2% for the same field points at -10 °C. Additionally, the OPD values for the on-axis field remain well within λ/4 for both sagittal and tangential planes across the entire operating temperature range. The system achieves a Strehl ratio significantly above 0.8 throughout this temperature range, ensuring high image quality.

For near-focus performance at 10m, the MTF drop remains below 5% at 20°C and across the temperature range of -10°C to +60°C, meeting the required performance criteria. The optical design successfully meets all specifications for operation in harsh environmental conditions, making it highly suitable for Gun scope applications.

The optical system designed for the gun scope consists of three lenses, as shown in Figure 2. The first lens (L1) is an aspheric element made of germanium, the second lens (L2) is a spherical element composed of zinc selenide, and the third lens (L3) is a spherical lens made of germanium [1]. Germanium has a Knoop hardness of 780 kg/mm², making it highly resistant to wear and environmental stress. Due to its durability, the first lens, being made of germanium, is well-suited for harsh operating conditions, ensuring reliability and longevity in demanding environments.

Table 3 presents the physical properties of germanium and zinc selenide. Germanium has a high Abbe number, indicating low dispersion, and a high refractive index. In contrast, zinc selenide has a lower Abbe number, meaning it exhibits higher dispersion than germanium, and its refractive index is also lower. The complementary optical properties of these materials make them well-suited for LWIR applications. In this design, a combination of germanium, zinc selenide, and germanium lenses is utilized to leverage their optical characteristics. Additionally, incorporating one aspheric surface helps minimize chromatic aberrations and effectively correct spherical aberration, ensuring optimal optical performance.

Germanium has a significantly high dn/dT value, as shown in Table 3, meaning its refractive index varies considerably with temperature. In contrast, zinc selenide has a significantly lower dn/dT value, resulting in minimal changes in refractive index due to temperature fluctuations. The combination of germanium and zinc selenide helps in athermalization by partially compensating for focus shifts caused by temperature-induced changes in refractive index and the expansion of the aluminum housing (CTE: 23×10^{-6} °C^{-1}) by using the material properties of both germanium and zinc selenide. However, complete compensation is achieved through active athermalization, where the third lens is adjusted to counteract the focus shift. The thermal glass constants for both germanium and zinc selenide are positive, indicating that the back focal length decreases as temperature increases and vice versa [2]. To correct this shift, the third lens in the design, shown in Figure 2, moves accordingly, towards the sensor (right) as temperature rises and away from the sensor (left) as temperature drops. This controlled movement ensures optimal focus across the entire operating temperature range, maintaining diffraction-limited performance.

Table 3: Physical properties of IR Materials in the LWIR region

Material	Refractive index (n) [9]			Abbe number $V = n_m - 1/ n_s - n_l$ [9]	dn/dT ($\times 10^{-6}$) (K^{-1}) [10]	Thermal expansion coefficient $\alpha \times 10^{-6}$ (K^{-1}) [10]	Thermal glass constant $\beta \times 10^{-6}$ (K^{-1}) [9]
	$\lambda = 8$ (μm)	$\lambda = 10$ (μm)	$\lambda = 12$ (μm)				
Germanium	4.00669	4.00432	4.00285	783.21	396	5.7	126
Zinc selenide	2.41728	2.40645	2.39281	57.48	61	7.1	36

Near-focus adjustment is also accomplished by the movement of the third lens, which fine-tunes the focus position to ensure optimal performance across the entire operating temperature range.

Performance Analysis:

The performance of the Gun scope optical design is evaluated using key analytical metrics that quantify its optical quality. The design demonstrates well-corrected performance, achieving an MTF value of 0.446 for the on-axis field and 0.44 for the 0.75 field point at the Nyquist frequency. The OPD values remain within λ/4, and the Strehl ratio exceeds 0.95 [1]. To ensure the optical system meets operational requirements, image quality metrics—including MTF, OPD, and Strehl ratio—are analyzed across the extreme temperature range of -10 °C to +60 °C, as well as for near-focus performance at 10 meters at 20 °C, +60 °C, and -10 °C.

The following section provides a detailed assessment of these image quality parameters under extreme environmental conditions and near-focus scenarios, evaluating the system's overall optical performance.

Performance Analysis at +60 °C Operating Temperature

At +60 °C, the back focal distance decreases due to material thermal expansion, as quantified by the glass thermal constant. To maintain optimal focus on the FPA plane, the third lens is shifted 1.57 mm toward the sensor. System performance is then analyzed using MTF, OPD, Strehl ratio, and image analysis with extended sources.

Modulation Transfer Function (MTF) Analysis: System performance is assessed based on the allowable 5% drop in MTF values at on-axis and 0.75 field positions. After refocusing at +60 °C, the MTF value for the on-axis field is 0.433, while at the 0.75 field point, it is 0.421. This corresponds to a drop of 2.91% from 0.446 for the on-axis field and 4.3% from 0.44 at the 0.75 field position, both within the acceptable limit of a 5% MTF drop at extreme temperature conditions.

Figure 3 illustrates the MTF across all wavelengths at different field points (on-axis, 0.5 FOV, 0.75 FOV, and full FOV) at the Nyquist frequency of 29.4 lp/mm.

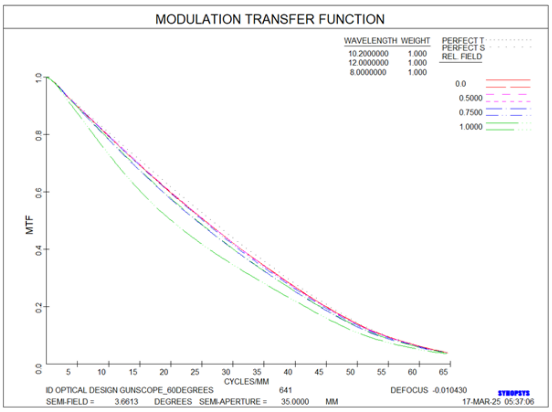

Figure 3: Polychromatic MTF at operating temperature of 60 °C

Optical Path Difference OPD: Optical Path Difference (OPD) is a critical parameter in evaluating optical systems, as it quantifies the phase variations introduced by the system. It plays a vital role in optimizing image quality and is instrumental in refocusing the design during athermalization analysis.

Figure 4 illustrates the OPD plots for the design wavelengths at different field positions, including on-axis, 0.5 FOV, 0.75 FOV, and full FOV, at an operating temperature of +60 °C. The results confirm that the system's OPD values remain well within λ/4 for the on-axis field in both sagittal and tangential planes, meeting the required performance criteria for extreme temperature conditions.

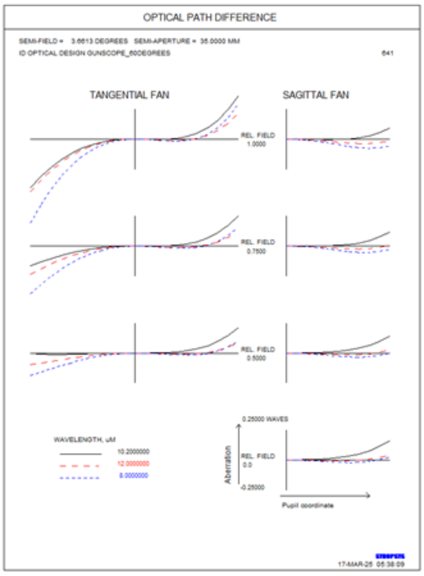

Figure 4: OPD plot at operating temperature of +60 °C

Strehl Ratio: The Strehl ratio is a fundamental metric used to assess the optical system's image formation quality. A higher Strehl ratio indicates good optical performance, ensuring sharp and highly accurate images. For acceptable image quality, the Strehl ratio should be at least 0.8.

Figure 5 shows the Strehl ratio curve for all designed wavelengths across the entire field of view after refocusing at +60 °C. The results indicate that the Strehl ratio exceeds 0.96 at the on-axis field point and remains above 0.87 at the full field. Since these values are significantly higher than the 0.80 threshold, the system operates at the diffraction limit, delivering exceptional image quality even under extreme temperature conditions.

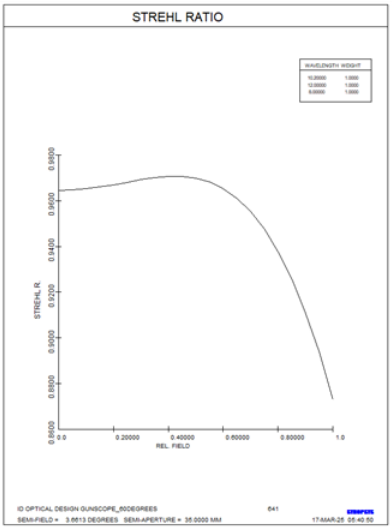

Figure 5: Strehl Ratio at operating temperature of +60 °C

Image Analysis with Extended Sources: SYNOPSYS™ provides an advanced Image Analysis Tool that simulates the impact of lens aberrations and diffraction on image quality using various test targets. These targets include sine wave, square wave, double star, circle, square, 3-bar, and AF target patterns.

Figures 6 and 7 display images of the double star and 3-bar test targets, respectively, captured through the Gun Scope optical design at the Nyquist frequency of 29.4 lp/mm at an operating temperature of +60 °C. These images demonstrate the system’s imaging performance and confirm its capability to maintain high-quality image resolution under extreme environmental conditions.

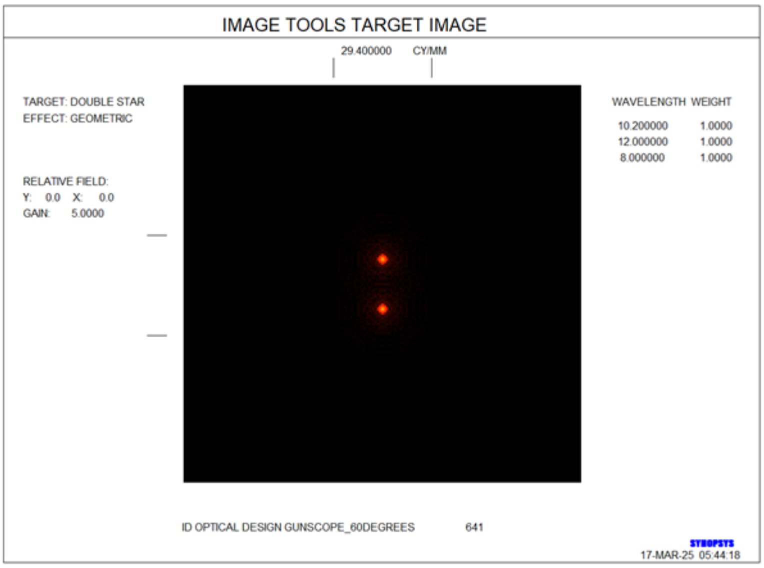

Figure 6: Image Analysis using Double Star Target at +60 °C

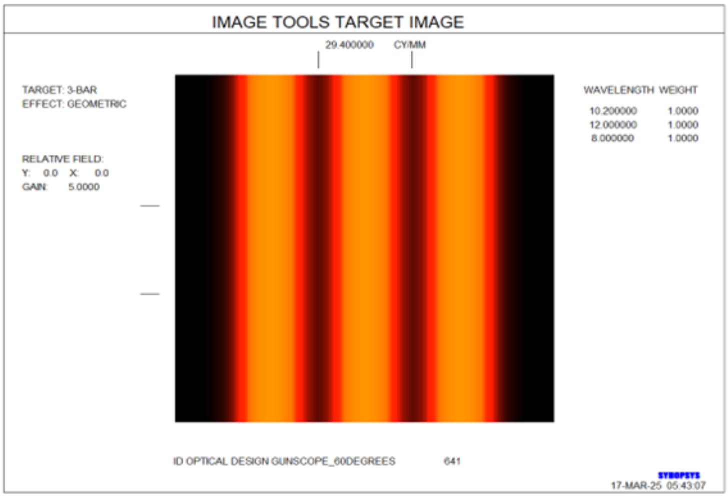

Figure 7: Image Analysis using 3 Bar Target at +60 °C

Performance Analysis at an Operating Temperature of -10 °C:

At an operating temperature of -10 °C, the back focal distance of the Gun Scope optical system increases, as determined by the Glass constant. To maintain optimal focus on the Focal Plane Array (FPA), the third lens is shifted 1.01 mm to the left, away from the sensor. The system’s performance is assessed using key optical metrics, including Modulation Transfer Function (MTF), Optical Path Difference (OPD), Strehl ratio, and image analysis with extended sources.

Modulation Transfer Function (MTF) Analysis: The system's performance is evaluated by measuring the drop in polychromatic MTF values at both the on-axis and 0.75 field points. After refocusing at -10 °C, the MTF value is 0.443 on-axis and 0.439 at the 0.75 field point. The MTF drop is 0.67% relative to the nominal 0.446 value for on-axis and 0.2% relative to the 0.44 value at the 0.75 field, both well within the acceptable 2% threshold for extreme temperature conditions.

Figure 8 presents the MTF across all wavelengths at various field points, including on-axis, 0.5 FOV, 0.75 FOV, and full FOV, at the Nyquist frequency of 29.4 lp/mm.

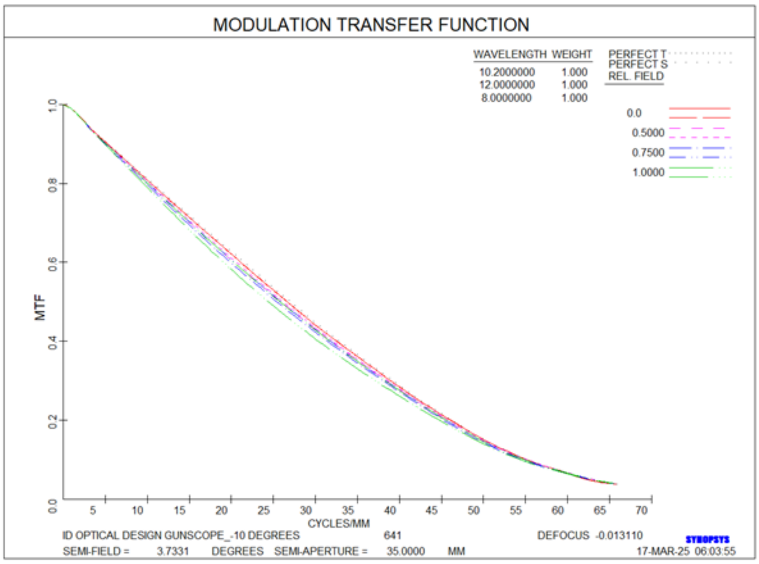

Figure 8: Polychromatic MTF at operating temperature of -10 °C

Optical Path Difference (OPD) Analysis: The OPD metric ensures that phase variations remain minimal across the optical system. The performance criterion requires that OPD values remain within λ/4 at the on-axis field for both sagittal and tangential planes.

Figure 9 shows OPD plots for different field positions—on-axis, 0.5 FOV, 0.75 FOV, and full FOV—at an operating temperature of -10 °C. The results confirm that OPD values are well within λ/4 for the on-axis field, meeting the required performance standards across the entire temperature range.

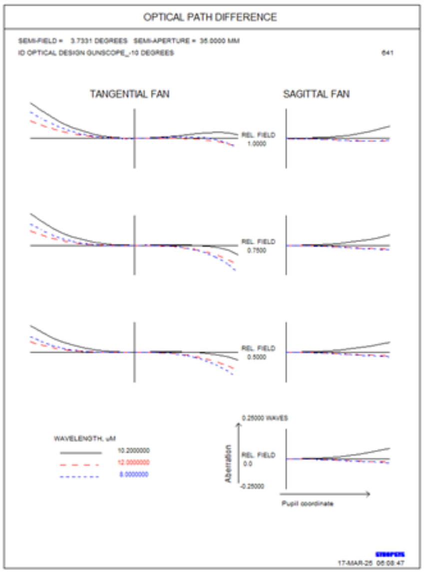

Figure 9: Optical Path Difference at operating temperature of -10 °C

Strehl Ratio: The Strehl ratio measures the optical system's ability to produce high-quality images. Figure 10 illustrates the Strehl ratio curve for all designed wavelengths across the full field of view after refocusing at -10 °C. The results show that the Strehl ratio exceeds 0.98 at the on-axis field and remains above 0.95 across the full field. Since these values are significantly higher than the 0.80 threshold, the system maintains diffraction-limited performance, ensuring exceptional image quality at temperatures as low as -10 °C.

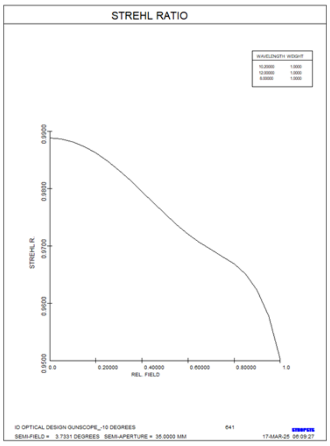

Figure 10: Strehl Ratio for operating temperature of -10 °C

Image Analysis Using Extended Sources: Figures 11 and 12 depict images of the double star and 3-bar test targets, respectively, as captured through the Gun Scope optical system at a Nyquist frequency of 29.4 lp/mm and an operating temperature of -10 °C. These images effectively demonstrate the system's ability to maintain high-resolution imaging performance under extremely low-temperature conditions.

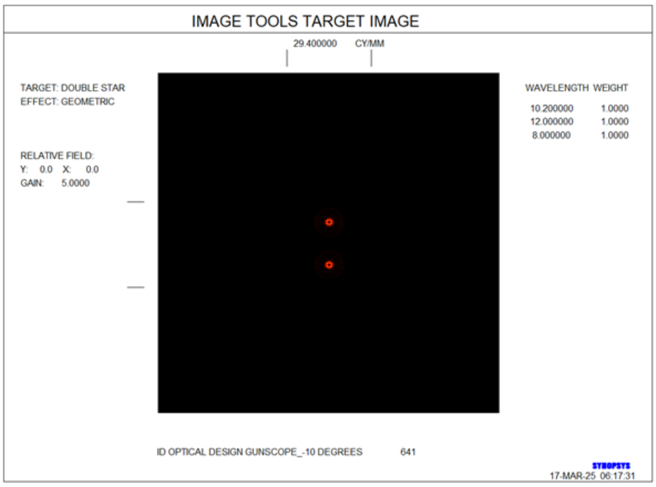

Figure 11 : Image Analysis using Double Star Target at -10 °C

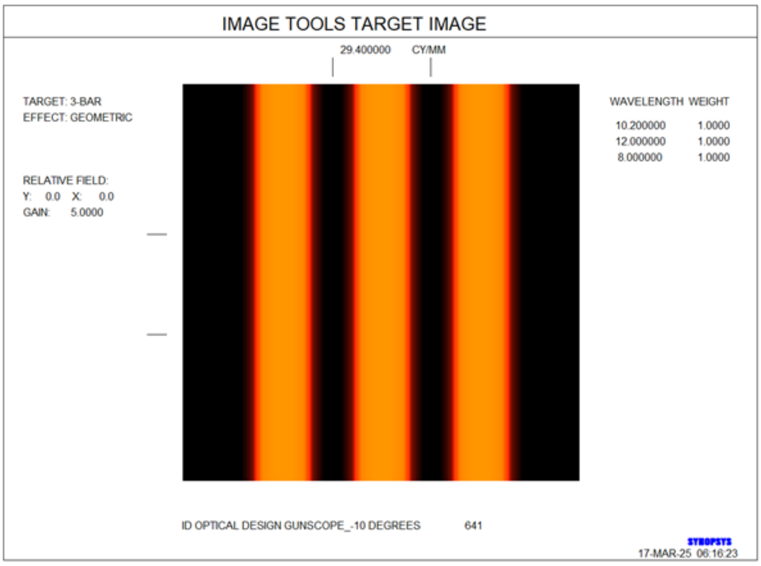

Figure 12: Image Analysis using 3 Bar Target at -10 °C

Near-Focus Performance Analysis at 10m:

Near-focus analysis is conducted at a distance of 10 meters under three different temperature conditions: 20 °C, +60 °C, and -10 °C. In each scenario, refocusing is achieved by adjusting the position of the third lens, either moving it closer to or farther from the sensor. The system's performance is evaluated based on a maximum permissible 5% drop in the on-axis polychromatic MTF value compared to its corresponding MTF value at infinity.

Near-Focus Performance at 10m and 20 °C:

When the object distance is reduced from infinity to 10 meters, the Gun Scope optical system is refocused by shifting the third lens 2.65 mm to the left, away from the sensor. This adjustment ensures optimal focus, keeping the on-axis OPD curve within one-quarter of a wavelength $\lambda/4$. At this new focus position, the on-axis polychromatic MTF value at the Nyquist frequency is 0.43, representing a 4.6% drop from the initial polychromatic MTF value of 0.446. This drop remains well within the acceptable 5% threshold.

Figure 13 illustrates the polychromatic MTF values across all field points, while Figure 14 presents the OPD curves for the near-focus condition at 10m and 20 °C.

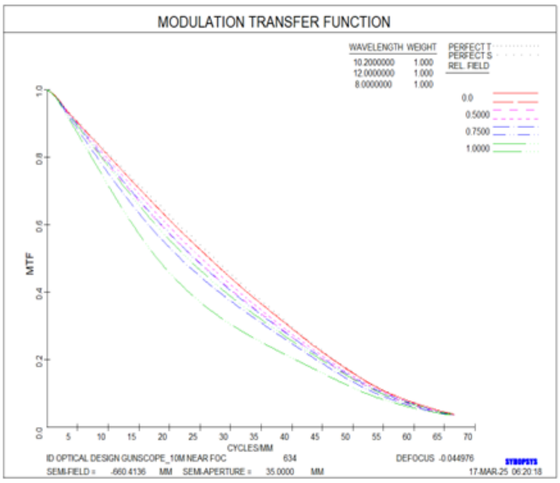

Figure 13: Polychromatic MTF for Near focus of 10m at 20 °C

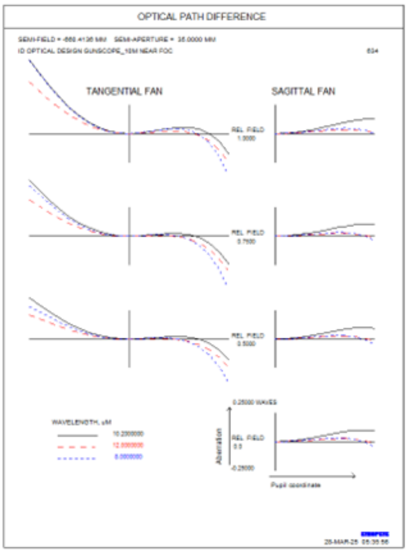

Figure 14: OPD for Near focus of 10m at 20 °C

Near-Focus Performance at 10m and +60 °C:

At extreme temperatures, near-focus analysis is essential to ensure the system maintains optimal performance under harsh conditions and captures critical details despite extreme environmental conditions. The near-focus evaluation at +60 °C involves two key steps: first, refocusing to compensate for the thermally induced focus shift, followed by adjusting the object distance from infinity to 10 meters.

To achieve optimal focus at this temperature, the third lens is shifted 2.89 mm to the left, away from the sensor. At this position, the on-axis OPD curve remains within λ/4. Interestingly, the on-axis polychromatic MTF value at the Nyquist frequency is measured at 0.447, showing a 3.1% increase compared to the original value of 0.434. This unexpected improvement in MTF, rather than the anticipated drop, can be attributed to the nonlinear interaction of design parameters influenced by temperature variations.

Figure 15 presents the polychromatic MTF across all field points, while Figure 16 illustrates the OPD curves for near-focus conditions at 10m and +60 °C.

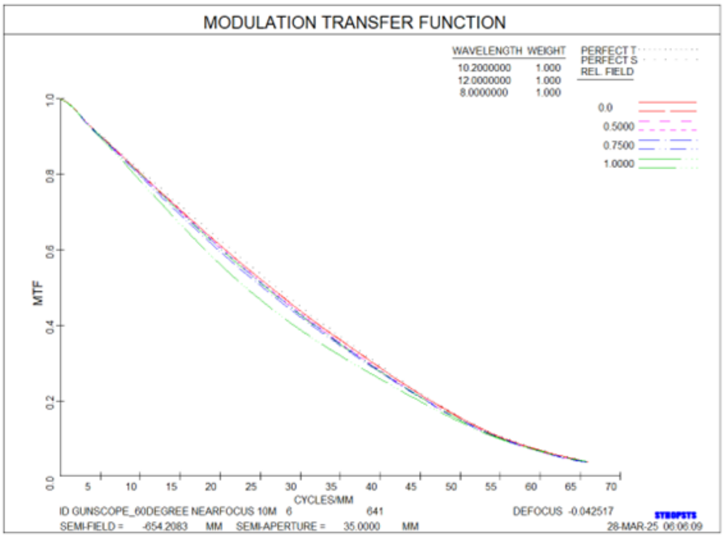

Figure 15: Polychromatic MTF for near focus of 10m at 60°C

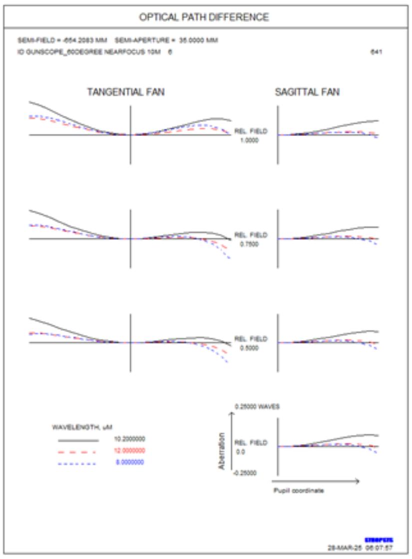

Figure 16: OPD for near focus of 10m at 60°C

Near-Focus Performance at 10m and -10 °C

For extreme low-temperature conditions (-10 °C), near-focus analysis follows a similar approach. Initially, the system is refocused to counteract the thermal-induced focus shift. Then, the object distance is adjusted to 10 m.

In this case, the third lens is shifted 2.6 mm to the right, towards the sensor, to achieve optimal focus. At this position, the on-axis OPD curve remains within λ/4. The on-axis polychromatic MTF value at the Nyquist frequency is 0.437, showing a minor 1.35% drop from the original 0.443 value. This reduction is well within the acceptable 5% limit, confirming the system's capability to maintain high performance even under extreme cold conditions.

Figure 17 illustrates the polychromatic MTF values for all field points, while Figure 18 presents the OPD curves for near-focus conditions at 10m and -10 °C.

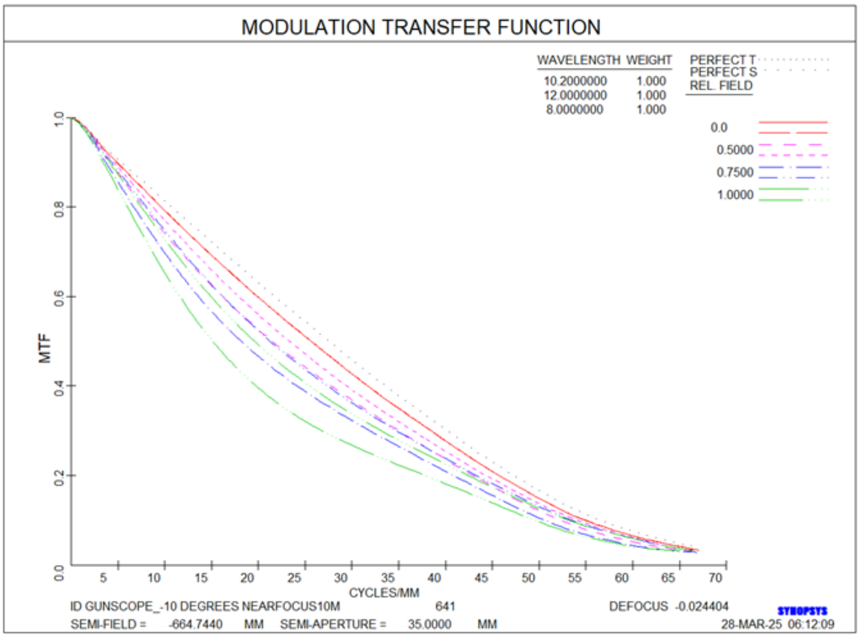

Figure 17: Polychromatic MTF for near focus of 10m at -10°C

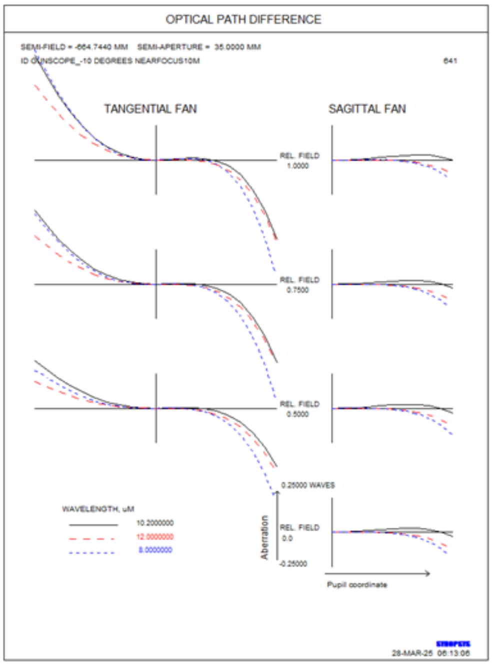

Figure 18: OPD for near focus of 10m at -10°C

IV. Conclusion

An optical system has been analyzed for a Gun scope application utilizing an uncooled microbolometer FPA-based sensor operating in the 8–12 µm wavelength range for extreme temperature conditions ranging from -10 °C to +60 °C, as well as near focus at temperatures of 20 °C and a range of -10 °C to +60 °C. The system exhibits well-corrected optical performance, achieving an MTF drop of less than 5% for on-axis and 0.75 field at the Nyquist frequency for an operating temperature of +60 °C and less than 2% for on-axis field and 0.75 field at the Nyquist frequency for an operating temperature of -10 °C. The OPD values for the on-axis field are well within λ/4 for both sagittal and tangential planes across the operating temperature range of -10 °C to +60 °C. The Strehl ratio is much greater than 0.8 for the entire operating temperature range, -10 °C to +60 °C. The MTF drop for near focus at 10m for 20 °C and the temperature range of -10 °C to +60 °C is less than 5%, meeting the performance criteria. The optical design fully meets the design criteria for the harsh environmental conditions, making it very suitable for Gun scope applications.

References

[1]. Faiqah Bint Monir, Kashif Ali Pervaiz, Design Of An Infrared Optical System For Gun Scope Application With An Uncooled Thermal Imaging Sensor In LWIR (8-12 µm) Region, ISOR Journal Of Applied Physics ISOR-JAP Volume 17 Issue 2, 10.9790/4861-1702020111

[2]. Dilworth D D SYNOPSYSTM User's Manual, Optical System Design, LLC. 2101 N. Country Club Rd, Suite 12, Tucson AZ 85716, USA

[3]. Norbert Schuster, Passive Athermalization Of Two-Lens-Designs In 8-12micron Waveband, Conference Paper In Proceedings Of SPIE - The International Society For Optical Engineering · May 2012 DOI: 10.1117/12.918112

[4]. Athermalization Of Optical Systems In Infrared, Ali H. Al-Hamdani† And Raghad I.Ibrahim, International Journal Of Current Engineering And Technology, Vol.5, No.5 (Oct 2015)

[5]. Robert E. Fischer, Biljana Tadic-Galeb &Paul R. Yoder "Optical System Design", 2nd Ed, (Mcgraw-Hill, New York), [2008].

[6]. Compact Athermalized LWIR Objective Lens, Hussein Mohammed Hassan, Tawfik Abd-Elhamed Eldessouky, Mohammed Medhat, J Opt (March 2023) 52(1):261–268, Https://Doi.Org/10.1007/S12596-022-00892-2

[7]. Daiker, J. T, "Athermalization Techniques In Infrared Systems", OPTI 521, (2010).

[8]. Faiqah Bint Monir, Kashif Ali Pervaiz, Image Quality Metric Analysis- A Core Design Perspective- For The Gun Scope Optical System With An Uncooled LWIR Thermal Imaging Sensor, IOSR Journal Of Applied Physics (IOSR-JAP) E-ISSN: 2278-4861.Volume 17, Issue 2 Ser. 2 (Mar. – Apr. 2025), PP 12-22, Www.Iosrjournals.Org, DOI: 10.9790/4861-1702021222

[9]. Max J. Riedl, "Optical Design Fundamentals For Infrared Systems", Second Edition, Tutorial Texts In Optical Engineering, Volume TT48, ISBN 0-8194-4051-50-8194-1935-4. [2001].

[10]. Riedl, M. J., [Optical Design Applying The Fundamentals], SPIE PRESS TT84, Bellingham, 73-88 (2010).