

Designing a high-performance eyepiece for a 0.97-inch OLED microdisplay

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ABSTRACT

The eyepiece is an essential component in optical equipment such as binoculars and optical sights; however, its design has received less research attention compared to objective lenses. In thermal imaging sights, images are displayed on a microdisplay and viewed through the eyepiece. OLED microdisplays, known for their high image quality, durability, reasonable cost, and common diagonal sizes (0.5, 0.6, and 0.97 inches), are increasingly adopted in both research and commercial optical systems. This paper presents a design methodology for an eyepiece tailored to a 0.97-inch microdisplay used in thermal imaging sights. Optical evaluation based on MTF, chromatic aberration, field curvature, and distortion demonstrates that the eyepiece meets the necessary requirements for viewing large-size microdisplays. The design is suitable for fabrication and integration into thermal sighting systems.

Keywords: Thermal sight; Eyepiece; OLED microdisplay; Optical design; MTF; Zemax.

1. INTRODUCTION

Thermal imaging technology has gained increasing attention due to its significant advantages in observation and targeting applications. As a result, thermal weapon sights have been extensively studied and widely deployed in the fields of defense and security [1, 2]. A typical thermal sight comprises five key components: a thermal objective lens, an infrared image sensor, a signal processing board, a microdisplay, and an eyepiece, as shown in figure 1. Among these, the microdisplay and the eyepiece play particularly crucial roles. The eyepiece, in particular, serves as the final optical link between the displayed image and the human observer, directly influencing the perceived image quality and overall system performance [3-5].

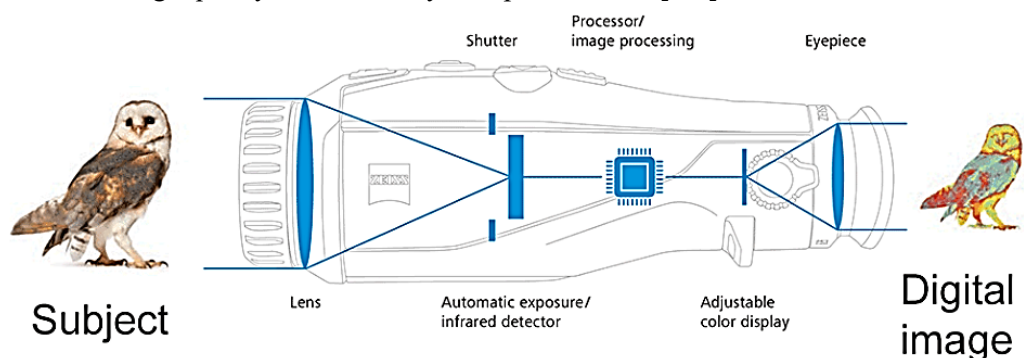


Figure 1. Optical layout of the thermal sight system.

In optical design, calculating eyepiece parameters is vital, as poor design can cause eye strain, reduce resolution, and distort images, degrading sighting device performance. The eyepiece largely affects the field of view and apparent magnification [6, 7]. A good design helps users track targets without excessive eye movement. Eye relief is critical for comfort and safety, especially for glasses wearers or in combat; insufficient relief causes vignetting or incomplete viewing. Poor design may induce distortion, chromatic aberration, spherical aberration, or astigmatism, impacting image quality in precision aiming systems. The eyepiece must also match the

microdisplay’s fixed size, resolution, and pixel layout to ensure proper image size and clarity. Thus, the eyepiece is a key component influencing the viewing experience, especially in modern microdisplay-based thermal sights. Optimal design improves overall optical system performance [6-9]. Recently, domestic research on binoculars, thermal sights, and multisensor systems has increased, mainly focusing on designing objective lenses: spherical, aspherical, stepped zoom, and continuous zoom types [10, 11]. However, eyepiece design for microdisplays remains limited despite its importance. OLED microdisplays, known for high image quality, low power, compact size, wide viewing angle, and fast response, commonly come in 0.5, 0.6, and 0.97 inches. The smaller sizes suit head-mounted sights, while the 0.97-inch is ideal for rifle sights, artillery, binoculars, and other display applications [12, 13].

Eyepiece design for microdisplays depends on screen size, which affects the field of view, eye relief, and resolution compatibility. Smaller screens need higher magnification, leading to shorter eye relief, narrower view, and increased aberrations requiring stricter quality control [6-9]. Larger screens allow lower magnification, longer eye relief, wider view, and simpler lens systems without sacrificing quality, improving comfort, especially for eyeglass users.

This paper presents a design method for a 0.97-inch microdisplay eyepiece in thermal weapon sights using Zemax. Section 2 details the design, section 3 evaluates optical quality, and section 4 concludes.

2. DESIGNING AN EYEPIECE FOR A 0.97-INCH MICRO OLED DISPLAY

In this section, the authors present the calculation of basic eyepiece parameters for a 0.97-inch OLED microdisplay based on input specifications of a thermal sight system. Starting from the initial optical parameters, Zemax software is used to design and evaluate the optical system quality after optimization, based on MTF, aberrations, field curvature, and distortion criteria [12-13].

2.1. The input parameters for the eyepiece design calculation

The eyepiece is designed to view images on the oled microdisplay, along with several specifications of the thermal sighting device, as shown in table 1 below:

Table 1. Input parameters for the eyepiece design calculation.

No.	Input parameters of the system	Value
1	Display type	Micro OLED display, RGB
2	Screen size	0.97 inch (24.64 mm)
3	Screen pixel size	24.6 μm
4	Screen resolution	800 x 600 pixel
5	Screen brightness	100 cd/m ²
6	Focal length of thermal lens	86 mm
7	Size of thermal detector	9.8 mm
8	Magnification	8 ^x
9	Eye relief	20 mm
10	Exit pupil diameter	6 mm

To design the eyepiece in Zemax software, the following basic parameters must be determined: focal length, field of view, eye relief, exit pupil diameter, brightness, and image quality.

2.2. Calculation of the design parameters for the eyepiece

The eyepiece focal length determines the magnification of the thermal sight. The magnification is calculated using the following formula [6-9]:

$$\Gamma = \frac{f_{VK} \cdot D_{OLED}}{f_{KM} \cdot D_{CORE}} \tag{1}$$

Where Γ , f_{VK} , f_{KM} , D_{OLED} , and D_{CORE} represent the magnification of the thermal sight, the focal length of the thermal objective lens, the focal length of the eyepiece, the OLED screen size, and the size of the thermal sensor, respectively. Thus, for the same values of the objective lens focal length, thermal sensor size, and OLED screen size, the smaller the focal length of the eyepiece, the greater the device's magnification. However, an eyepiece with a smaller focal length is more challenging to design than one with a larger focal length. From equation (1), the focal length of the eyepiece is calculated as follows:

$$f_{KM} = \frac{f_{VK} \cdot D_{OLED}}{\Gamma \cdot D_{CORE}} \quad (2)$$

Once the focal length f_{KM} is determined, its field of view is calculated as follows [6-10]:

$$2\omega = 2 \cdot \arctan\left(\frac{D_{OLED}}{2 \cdot f_{KM}}\right) \quad (3)$$

From formula (3), it can be seen that a larger field of view requires either a larger screen size or a smaller eyepiece focal length. To facilitate target observation and enhance magnification, a large 0.97-inch OLED screen is used. However, the larger screen size presents a design challenge, as the eyepiece must ensure uniform image quality across the entire field of view.

By substituting the values from table 1 into formulas (2) and (3), the design parameters of the eyepieces are obtained as follows: $f_{KM} = 27$ mm, $D_{OLED} = 24.64$ mm, $2\omega_{KM} = 49^\circ$, and $D_{KM} = 6$ mm.

3. RESULTS AND DISCUSSION

In this section, based on the previously calculated basic design parameters of the eyepiece, the optical system of the eyepiece is designed using Zemax software. The optical quality is evaluated based on criteria such as MTF transfer function, chromatic aberration, field curvature, and image distortion, and is compared with an eyepiece optical system previously designed for a 0.6-inch microdisplay [12].

3.1. The results of the eyepiece optical system design using Zemax

Using Zemax design software [14], the starting optical system of the eyepiece is set with the basic parameters: $f_{KM} = 27$ mm, $D_{OLED} = 24.64$ mm, $2\omega_{KM} = 49^\circ$, and $D_{KM} = 6$ mm as calculated above. After performing the design and optimization steps, the resulting optical system design of the eyepiece is shown in figure 2:

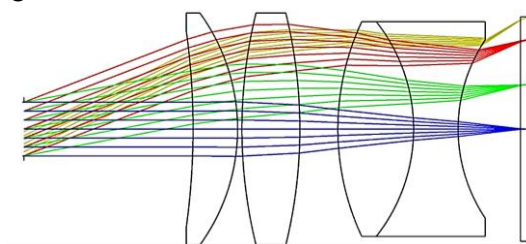


Figure 2. The structural diagram of the eyepiece optical system in Zemax.

The optical system of the eyepiece is designed with three lenses, one of which is a cemented lens made from two separate lenses. The evaluation of the optical system quality after design, based on the criteria established in [10-12], is presented as follows.

3.2. Evaluation of eyepiece optical system quality

3.2.1. The Modulation Transfer Function (MTF)

Since eyepiece optical systems work directly with the human eye, image quality evaluation primarily focuses on contrast and resolution. Therefore, when designing eyepiece optics positioned

after a microdisplay, the Modulation Transfer Function (MTF) serves as the foremost and most critical criterion for assessing the image quality produced by the system. The MTF of the eyepiece system is illustrated in figure 3 as follows:

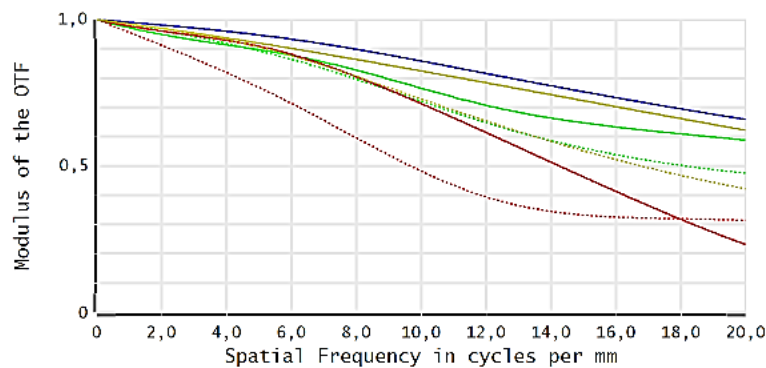


Figure 3. MTF of the eyepiece.

According to [12], the optical system of the eyepiece must be designed to meet the quality corresponding to the resolution of the microdisplay, and the spatial frequency to be examined is determined by the resolution of the microdisplay. The frequency corresponding to the resolution of the microdisplay depends on the pixel size, referred to as the Nyquist frequency, and is calculated using the formula $\nu = 1/(2 \cdot Q)$. With $Q = 24.6 \mu\text{m}$, we calculate $\nu_{\text{OLED}} = 20.33 \text{ lp/mm}$. Therefore, it is necessary to examine the MTF value of the eyepiece optical system at a frequency of 20.33 lp/mm .

According to the definition, the MTF value is the ratio between the contrast of the image and the contrast of the object [10-12]. Therefore, for a given MTF value at the examined frequency, we cannot be certain about the contrast of the image (since it also depends on the contrast value of the object). As a result, no specific threshold criterion for the MTF value is mentioned in the optical design literature. In this case, we consider a Foucault test object consisting of black-and-white lines with an absolute contrast of 1. Under this condition, the minimum threshold value of the MTF that should be achieved at the frequency determined above is 0.2 (Rayleigh criterion, Foucault criterion [10-12]).

By referring to the graph in figure 3, it can be observed that the designed eyepiece optical system achieves an MTF value of 0.5 at a spatial frequency of 20 mm^{-1} for on-axis rays and 0.25 for marginal rays. These values meet the image quality criterion for MTF performance, which requires a value greater than 0.2 [10-12].

3.2.2. Longitudinal chromatic aberration

Chromatic aberration is caused by the dispersive properties of optical materials. It occurs for both on-axis and off-axis objects. Based on these two positions, chromatic aberration is categorized into two types: axial (or longitudinal) chromatic aberration and lateral chromatic aberration [10]. For eyepiece systems used to observe microdisplays, the magnitude of lateral chromatic aberration has a greater impact on the perceived image quality. The graph in figure 4 shows the lateral chromatic aberration of the eyepiece system designed by the authors for a 0.97 -inch microdisplay.

Based on the resolving power of the human eye, in order for chromatic aberration to be imperceptible, the angle formed by the maximum lateral chromatic displacement must be smaller than the eye's angular resolution limit (α_m). Under this condition, the human eye will no longer detect the presence of chromatic aberration. Specifically, for eyepiece systems, the value of lateral chromatic aberration Δ must be smaller than this threshold: $\Delta \leq f_{\text{KM}} \cdot \tan(\alpha_m) = 27 \cdot \tan(1') = 7.85 \mu\text{m}$. By referring to the graph in figure 4, it can be observed that the designed optical system exhibits a lateral chromatic

aberration value of approximately $7.7 \mu\text{m}$, which is less than $7.85 \mu\text{m}$, within 96% of the field of view. Therefore, the designed optical system meets the chromatic aberration requirement.

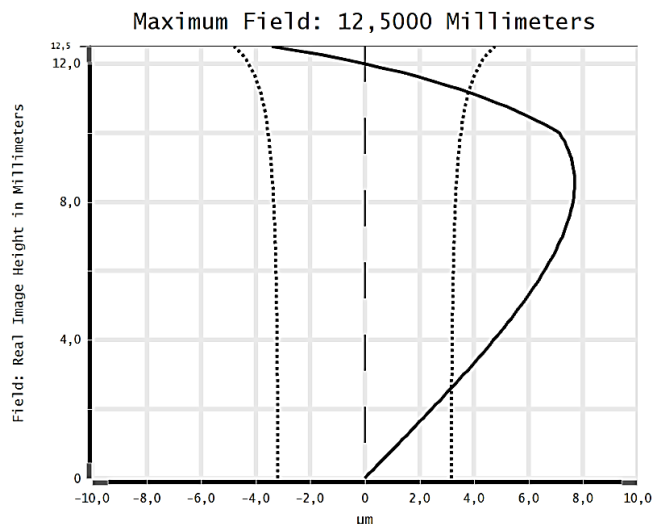
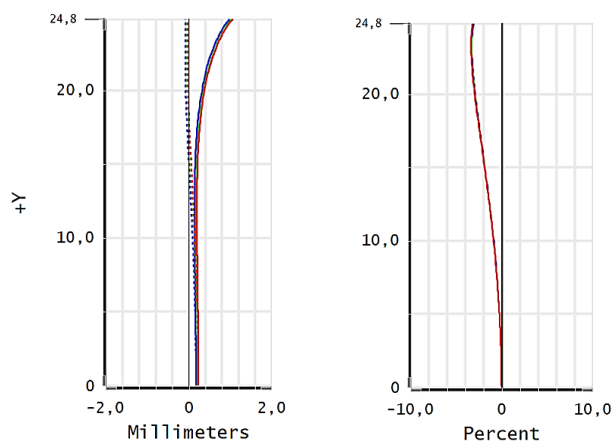


Figure 4. Graph of lateral chromatic aberration.

3.2.3. Field curvature and distortion

Astigmatism and field curvature are two closely related aberrations in an optical system [10-12], and are therefore often analyzed together. In professional optical design software such as ZEMAX, these aberrations are routinely calculated and visualized. Figure 5 shows the field curvature and distortion plots of the designed eyepiece optical system for a 0.97-inch microdisplay.

Although the human eye has a good accommodation capability, this ability decreases with age. Therefore, in optical system design, astigmatism and field curvature must be optimized to remain within the accommodation range of individuals aged 50-60. For a 50-year-old person, the near point is approximately 400 mm [10-12], which corresponds to a change in the eye's focal length from 22.875 mm to 21.557 mm [10-12]. This results in an allowable accommodation range of 1.318 mm. Consequently, the astigmatism and field curvature values of the eyepiece system used for the microdisplay must not exceed 1.318 mm. Referring to the field curvature plot in figure 5a, the designed eyepiece system exhibits a maximum field curvature of less than 1.1 mm, which satisfies this design requirement.



a. Field curvature. b. Distortion.

Figure 5. Graph of field curvature and distortion.

Optical distortion refers to the displacement of an image relative to the position it would occupy in an ideal optical system. Therefore, in the case where distortion is the only aberration present (with all other aberrations being zero), a point object will still be imaged as a point, but its position will be shifted relative to the ideal image location. Distortion depends on the object height; objects located on the optical axis do not produce distortion. A typical optical system introduces two types of distortion: barrel distortion (negative distortion) and pincushion distortion (positive distortion). The magnitude of distortion is usually expressed as a percentage. Figure 5b shows the distortion plot of the eyepiece optical system designed by the authors.

Distortion becomes imperceptible to the human eye when it remains within the range of 5 to 10%. For most modern optical devices, distortion values within this range are considered acceptable. In the case of night vision systems based on image intensification principles, the distortion across the full field of view must not exceed 4% in order to meet quality standards. For eyepiece systems designed to observe microdisplays, the observed objects typically have rectangular shapes with straight edges, unlike the circular patterns common in other optical devices, thus requiring more stringent distortion control. According to [12-16], the distortion of eyepiece optics for microdisplay observation must not exceed 3%. Referring to the distortion plot in figure 5b, the designed system exhibits a distortion value of approximately 2.96% (<3%), thereby satisfying the distortion requirement.

Table 2. Results of the evaluation of the quality of the designed eyepiece optical system.

No.	Evaluation criteria	Required value	Achieved	Evaluation
1	MTF at a spatial frequency of 20.33 lp/mm	> 0.2	0.25	Good
2	Lateral chromatic aberration	< 7.85 μ m	7.7	Good
3	Field curvature	<1.318mm	1.1	Good
4	Distortion	< 3%	2.96%	Good

In summary, the designed eyepiece optical system for the 0.97-inch microdisplay meets all four key image quality criteria specified in [12-16], including MTF performance, chromatic aberration, field curvature, and distortion, as summarized in table 2. The design results are suitable for use in the fabrication of eyepiece optics for thermal imaging sights.

For the optical system eyepiece with $f_{KM} = 22$ mm designed for a 0.6-inch microdisplay ($D_{OLED} = 15.2$ mm), the evaluation results are summarized in table 3 below:

Table 3. Quality evaluation results of the 0.6-inch microdisplay eyepiece system.

No.	Evaluation criteria	Required value	Achieved	Evaluation
1	MTF at a spatial frequency of 33.33 lp/mm	> 0.2	0.36	Good
2	Lateral chromatic aberration	< 6.4 μ m	8.3	Not good
3	Field curvature	<1.318mm	0.4	Good
4	Distortion	< 3%	2.2%	Good

Thus, the magnification chromatic aberration criterion for the eyepiece designed for the 0.6-inch microdisplay does not meet the requirements. This is due to the limited selection of glass materials used, making it impossible to meet this criterion.

A comparison with the 28mm EFL Mounted, RKE Precision Eyepiece by EO Edmund Optics shows that its configuration closely matches the one developed by the research team (figure 6). With a 28mm focal length, apparent field 45°, it has 5% distortion and 0.018 lateral color at 70% of the field of view [17], indicating that the designed eyepiece achieves optical quality on par with international products.

Based on the quality assessment results of the eyepiece optical system designed for the 0.97-inch display and the previously designed system for the 0.6-inch display, the 0.97-inch eyepiece

optics successfully met all evaluation criteria. This confirms its suitability for use in thermal imaging sights employing a 0.97-inch microdisplay.



Optical Properties

Distortion (%):	5 (Specified @ 0.7 Field)
Effective Focal Length EFL (mm):	28.00
Field Stop Diameter (mm):	23.3
Apparent Field (°):	45.00
Back Focal Length BFL (mm):	15.67
Lateral Color, 0.7 Field :	0.018
Spot Size (μm):	3/13 (On-Axis/0.7 Field)

Figure 6. Optical properties of 28mm EFL-mounted, RKE precision eyepiece [15].

4. CONCLUSIONS

This paper proposes a method for the design, calculation, and quality evaluation of an eyepiece optical system for observing a 0.97-inch microdisplay, intended for use in thermal imaging sights. Using the optical design software Zemax, the eyepiece was designed with three lens elements, including one cemented doublet composed of two individual lenses. The optical quality of the eyepiece system was assessed based on four key criteria: MTF, chromatic aberration, field curvature, and distortion. The evaluation results show that the eyepiece designed for the 0.97-inch microdisplay meets all performance requirements, confirming its suitability for fabrication and application in thermal imaging sights. In contrast, an evaluation of a previously published eyepiece design for a 0.6-inch microdisplay revealed that it failed to meet chromatic aberration standards due to limitations in the glass materials used. The results presented in this paper contribute significantly to the research and development of eyepiece systems for larger microdisplays, highlighting their potential applications in optical targeting and observation devices mounted on military platforms in Vietnam.

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TÓM TẮT

Thiết kế kính mắt hiệu suất cao cho vi màn hình OLED kích thước 0,97 inch

Kính mắt là thành phần thiết yếu trong các khí tài quang học như ống nhòm, kính ngắm, song các nghiên cứu thiết kế còn hạn chế so với vật kính. Trong kính ngắm ảnh nhiệt, hình ảnh được hiển thị trên vi màn hình và quan sát qua kính mắt. Vi màn hình OLED với chất lượng hiển thị cao, độ bền tốt, chi phí hợp lý và kích thước phổ biến (0,5; 0,6; 0,97 inch) đang được ứng dụng rộng rãi. Bài báo trình bày phương pháp thiết kế kính mắt cho vi màn hình 0,97 inch dùng trong kính ngắm ảnh nhiệt. Kết quả đánh giá hệ quang kính mắt sau thiết kế dựa trên các tiêu chí hàm MTF, sắc sai, cong trường và méo ảnh cho thấy kính mắt được thiết kế đáp ứng được các yêu cầu để quan sát hình ảnh trên vi màn hình kích thước lớn 0,97 inch, có thể sử dụng kết quả thiết kế để gia công chế tạo hệ quang kính mắt sử dụng cho kính ngắm ảnh nhiệt.

Từ khóa: Kính ngắm ảnh nhiệt; Kính mắt; Vi màn hình OLED; Thiết kế quang học; MTF; Zemax.