Application Note

TI DLP® System Design: Optical Module Specifications

ABSTRACT

The objective of this application note is to help product developers better understand optical module specifications and related system design considerations. This information helps expedite product development and conversations with optical module manufacturers (OMM).

This document focuses on projection optical modules that incorporate Texas Instruments' DLP Display chips and are designed to project an image onto a surface for a variety of applications, including smartphones, tablets, display projectors, smart home displays, digital signage, AR glasses, and more.

Prior to reading this application note, it is recommended to read the Getting Started with DLP Display Technology application note.

The DLP Optical Design Guidelines presentation is mentioned throughout this application note. The presentation provides a comprehensive overview of the guidelines specific to designing an optical system with DLP Products and enables customers throughout the design process.

Please note that the terms *optical engine* and *light engine* are sometimes used in the projection industry. For consistency, this document uses the term *optical module*.

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1 Introduction to Optical Modules

An optical module (see Figure 1-1 and Figure 1-2) is the core sub-system of a DLP Display display system. A projection optical module consists of five main hardware components:

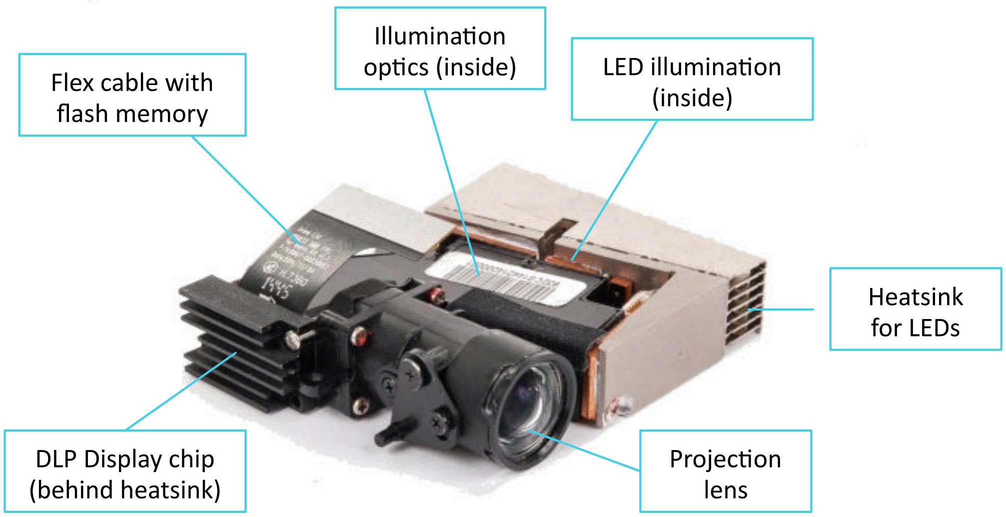


Figure 1-1. Example DLP2010 Projection Optical Module - Dimensions: 44 × 48 × 14mm^3

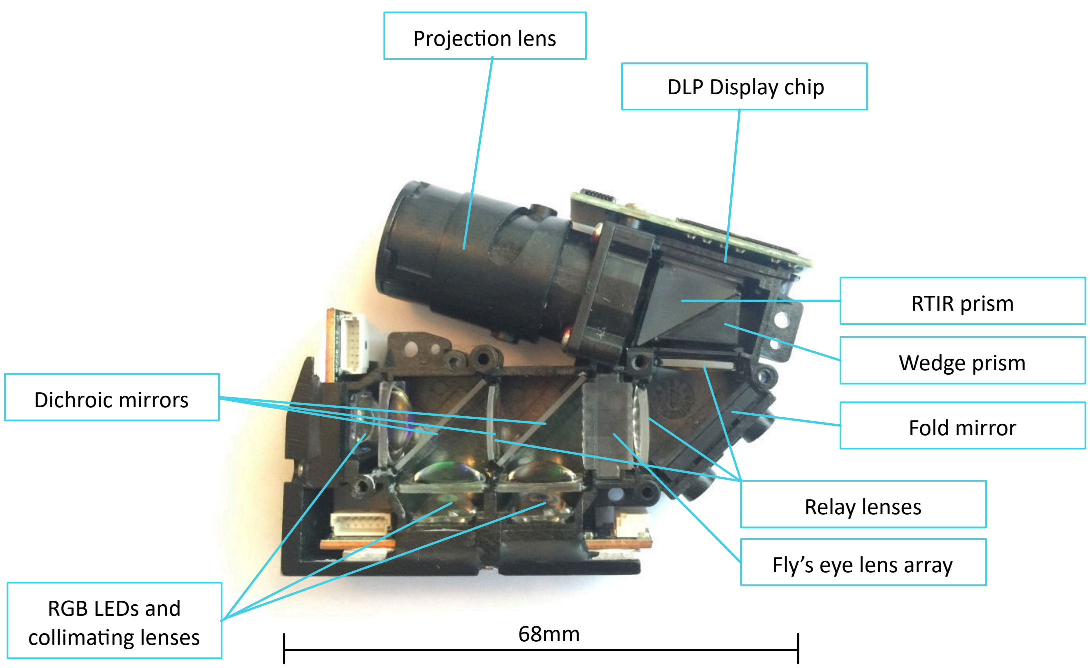


Figure 1-2. Optical Components in a Display Projection Optical Module - Dimensions: 68 × 57 × 15mm^3

1.1 DLP Display Chip or Digital Micromirror Device (DMD)

A micro-electro-mechanical system (MEMS) device with up to millions of micromirrors that rapidly switch to create projected pixels of different color and intensity when modulated in sync with color sequential illumination. For more detailed information pertaining to Optical Properties of a DMD, refer to slides 12 - 27 of the DLP Optical Design Guidelines presentation.

1.2 Illumination

DLP technology is compatible with all visible light illumination sources, such as HID lamps, RGB LEDs, direct laser, laser/LED hybrid, and laser-phosphor illumination. DLP Display projection optical modules use RGB LED illumination because of the compact size and high brightness efficiency, while laser phosphor illumination is used to achieve even higher brightness levels with compact optical designs. Additionally, direct laser illumination is employed to achieve wider color gamuts and higher contrast in an optical module.

Optical module manufacturers assist in choosing the appropriate illumination type based on system requirements. For more detailed information regarding light source illuminators and the impact on optical systems, refer to slides 31 - 45 of the DLP Optical Design Guidelines presentation.

1.3 Illumination Optics

Illumination optical components, such as lenses, beam mixing optics (such as fly's eye or light tunnel), fold mirrors, prisms, and dichroic mirrors, collect light from the illumination source and guide the light onto the DMD at the appropriate angle. For detailed information related to illumination optics and the impact optical systems, see slides 28 - 73 of the DLP Optical Design Guidelines presentation.

1.4 Projection Optics

Projection optical components collect light reflected by the DMD and then projects and focuses the light onto a surface at some distance from the final optical component. For more detailed information pertaining to projection optics, see slides 65 - 73 of the DLP Optical Design Guidelines presentation.

1.5 Flash Memory Board

The flash memory board is a small board typically attached to either the module or the flex cable connecting the DMD and DLP controller. DLP image processing settings specific to the optical module are stored in the flash memory and are used by the DLP controller during configuration of the system.

TI manufactures and sells the DLP chipset, which includes a DMD, controller IC, and power management IC (PMIC). Of these three components, only the DMD is included in the optical module (the controller and PMIC are integrated on a nearby printed circuit board or PCB).

TI offers a portfolio of DMDs that enable different classes of optical modules (view and compare the DLP Display & Projection Chipsets). Optical modules are designed and manufactured by third party companies (see Figure 1-3). Customers can source a pre-existing, tooled optical module from an optical module manufacturer (OMM) to speed design time and go to market faster. Alternatively, custom optical modules can be designed by an OMM with additional time and resources. The optical module ecosystem is robust, with OMMs worldwide that supply a variety of optical modules in high volumes.

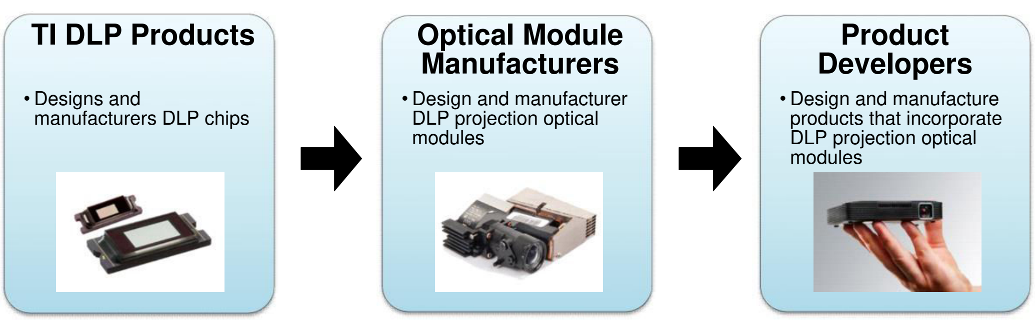


Figure 1-3. Supply Chain from TI DLP Chip to Product

2 Core Optical Module Specifications

The following projection optical module specifications are important and applicable to most applications.

2.1 Brightness

The brightness of an optical module is measured in lumens and indicates how much light is emitted from the projection lens when the illumination source is at peak output and displaying a white image (all DLP micromirrors are in the *on* position). Higher brightness modules project clearer images in bright ambient lighting by creating a greater difference in brightness between the projected content and the background projection surface.

Higher brightness usually involves tradeoffs such as a larger module size and increased power consumption. However, DLP technology's high optical efficiency minimizes these tradeoffs, enabling greater brightness in smaller, more power-efficient optical modules.

Brightness of an optical module varies as the white point (such as the relative mix of red, green, and blue light that creates white light) is adjusted. For the most accurate measure of performance, brightness should be specified with a target white point. For example, D65 (6500 K) is an industry standard.

To learn more about brightness specification and its impact on system tradeoffs, read the DLP Optical Design Guidelines presentation and the Brightness Requirements and Tradeoffs application note.

2.2 Size

DLP Displays projection optical modules vary in size (see Figure 2-1), accomadating a wide range of application. The size of a DLP optical module primarily depends on the DMD size (see Figure 2-2), optical design, and illumination size. In general, optical module size increases with brightness capability. Modules may include heat sinks, with one typically on the DMD and another on each LED. The size of the heat sink is mainly driven by the power consumption and efficiency of the illumination in the optical module.

Performance requirements and optical design layout affect the size and shape of an optical module. Light can be folded (that is, bounced back and forth off mirrors) to reduce specific dimensions such as depth or height. Additionally, the projection lens size is affected by the throw ratio and image offset: shorter throw ratios and higher offsets typically result in lager modules. For additional information on projection lens considerations, see slides 65 - 73 of the DLP Optical Design Guidelines presentation.

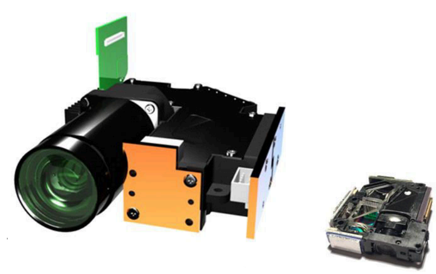


Figure 2-1. 75-mm DLP4501 Optical Module (left) compared to a 25-mm DLP2010 Optical Module (right)

Figure 2-2. 0.2-inch DLP2010 Diagonal DMD compared to a 0.45-inch DLP4501 Diagonal DMD

2.3 Resolution

The resolution of an optical module is determined by the DMD used within the system. While higher resolution optical modules involve system tradeoffs related to size and cost, ongoing advancements in DLP technology facilitate the development for increased resolutions in compact and affordable optical solutions.

One example would be to use XPR (Extended Pixel Resolution) technology for resolution enhancement. XPR uses high speed capabilities from the DMD used in the optical system to facilitate advanced pixel shifting which enhance image resolution. See slides 74 - 76 of the DLP Optical Design Guidelines presentation for detailed information related to resolution enhancements and impact on optical systems.

2.4 Illumination Power Consumption

The power consumption of a DLP Display projection system is primarily driven by the illumination source in the optical module and is typically measured in watts.

For RGB LED-illuminated optical modules, the power consumption specification includes all three LEDs (red, green, and blue). The LEDs can be driven to a maximum current and temperature specified by the LED manufacturer. Total LED power consumption depends on the LED drive current and duty cycle for each color.

The 4th channel blue pump LED is used to enhance the output of the green LED, resulting in increased brightness without increasing the power consumption for the other channels. The 4th channel blue pump LED must synchronize with the green LED for proper color mixing, allowing for brightness adjustments while maintaining color accuracy. Synchronization also improves efficiency, reduces flicker, and contributes to lower overall power consumption with reduced energy costs.

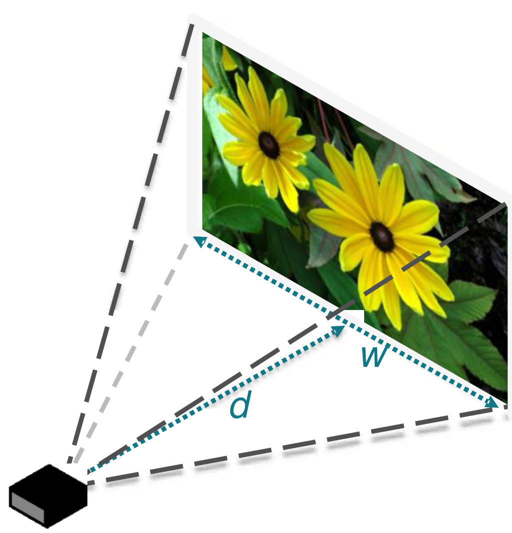
Additional examples of various illumination sources and the impacts to brightness, color performance, and efficiency in an optical module are discussed in detail from slides 32 - 45 of the DLP Optical Design Guidelines presentation.

2.5 Throw Ratio

Throw ratio (see Figure 2-3) describes how large of a projected image an optical module creates at a given distance from the projection surface. The throw ratio is defined as the ratio of D (the distance from the final optical element to the projection surface) to W (width of projected image). For example:

- Optical module with a throw ratio of 1.4 projects a 17” wide projected image from 24” away
- Ultra-short throw optical module with a throw ratio of 0.3 projects an 80” wide projected image from 24" away

A shorter throw ratio requires larger projection lenses and mirrors, increasing the size of the optical module. For more information regarding throw ratio, see slide 69 of the DLP Optical Design Guidelines presentation.



$$Throw\ ratio = \frac{(d)distance\ from\ projection\ lens\ to\ the\ image}{(w)horizontal\ width\ of\ the\ image}$$

Figure 2-3. Throw Ratio

2.6 Offset

Offset describes the projected light path after light exits the projection lens. A 0% offset means the light is evenly distributed above and below the lens axis after exiting the projection lens. A 100% offset keeps the top of the image aligned with the lens axis keeping the bottom of the image coincident with the projection lens axis. A 100% or higher offset (for example, tilted up) is most common in order to avoid sending the bottom part of a projected image into the surface on which the product is resting. However, some applications prefer a 0% offset, allowing for thinner optical modules. For more information regarding lens offset, refer to slide 70 of the DLP Optical Design Guidelines presentation.

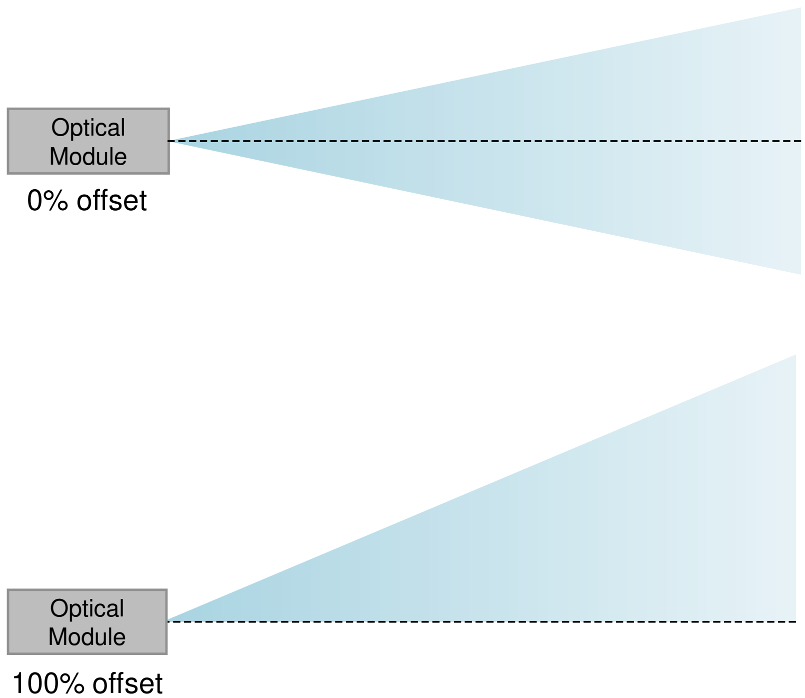


Figure 2-4. 0% Offset and 100% Offset

2.7 Contrast Ratio

There are two main methods for measuring projection system contrast: Full On / Full Off (FOFO) and checkerboard patterns, such as the IEC 61947 contrast standard (ANSI contrast). FOFO contrast is more commonly used by optical module manufacturers.

FOFO contrast measures the ratio of brightness between a fully white versus black projected image. The checkerboard pattern method measures contrast using a 4 × 4 array of black and white rectangles. Both methods normalize the measurement to a *x to 1* ratio.

When measuring contrast, FOFO is impacted by the inherent contrast ratio of the DMD as a function of the illumination and projection optic characteristics and design (for example, wavelength, F/#'s, illumination angle, and so forth). Checkerboard patterns are influenced by both the inherent contrast of the DMD and the contrast performance of the projection optics. FOFO has higher contrast ratios than checkerboard patterns. Additionally, checkerboard contrast serves as a more accurate indicator of the true contrast performance of an optical module when displaying video content.

One effective method to improve contrast ratios in an optical module is through Stray Light Mitigation. While off-state light is typically redirected away from the projection lens, managing this light effectively is crucial to prevent the light from re-entering the system. Contrast degradation and image artifacts can result from stray light entering the projection lens pupil within the field of view of the DMD active array, particularly when mirrors are in the off-state. The primary causes of stray light in DLP projectors include: light scattering from optical components and mechanical structures, mismatched illumination or projection lens pupil configurations, and light scattering from the DMD mirror structure.

Higher contrast optical modules create a more vibrant, colorful projected image, while lower contrast optical modules appear washed out (see Figure 2-5). For more detailed information regarding contrast and methods on stray light mitigation in an optical system, see slides 24 - 27 (contrast) and 84 - 98 (stray light mitigation) of the DLP Optical Design Guidelines presentation.

Figure 2-5. Simulation of a High Contrast Projected Image (above) and a Low Contrast Projected Image (below)

3 Additional Optical Module Specifications

The following specifications, though not always essential, can be critically important in some applications.

3.1 Brightness Uniformity

Brightness uniformity describes the variation of brightness levels across different areas of a projected image. To measure brightness uniformity, an all-white image is projected, and then illuminance (lux) is measured at nine equally spaced points arranged in a 3 × 3 array across the image. Brightness uniformity is then calculated as:

$$\text{Brightness uniformity} = \left[\frac{\text{(lux of the dimmest point)}}{\text{average lux}}\right] \div \left[\frac{\text{(lux of brightest point)}}{\text{average lux}}\right] \quad (1)$$

Brightness uniformity at 100% describes a perfectly uniform projected white image with equal brightness levels at each point. In DLP Display projection optical modules, brightness uniformity typically ranges from 70% to 90% due to variations in optical component performance, size constraints, and optical misalignment.

Vignetting can also be intentionally introduced within the projection lens as a cost-saving measure. However, this approach often compromises both uniformity and efficiency in the optical performance. While vignetting can lower production expenses, the resulting decrease in light distribution and image quality must be carefully considered in the overall design and application of the projection lens.

The importance of brightness uniformity depends on the application and image content being projected. For instance, while low brightness uniformity is more likely to go unnoticed in typical movie or television shows, it is evident in high-contrast or detailed images.

3.2 Focus Uniformity

An ideal projection optical module has perfect focus uniformity, meaning the entire image is in focus. If an optical module has focus non-uniformity problems, the image is visibly out of focus in at least one location, often the edges or corners. Utilizing optical modules with higher F/#'s improves depth of focus and results in a more uniform focus throughout the projected image. Proper alignment of the projection optics with the DMD in the optical module is crucial to prevent issues (such as boresighting). These problems can stem from variations in optical component performance or optical misalignment. To learn more regarding focus uniformity and its impact on an optical system, see the DLP Optical Design Guidelines presentation.

3.3 Color Management

The color gamut of a display system indicates the range of colors the display system produces, defined by the three additive primary colors: red, green, and blue. In an LED-illuminated optical module, the range is determined by the colors of the individual LEDs and filters used in the system. The color gamut is traditionally plotted in the 1931 CIE chromaticity space.

Most optical module projectors conform to one of the following color gamut standards: Rec.709 (also known as BT.709), DCI-P3, and Rec.2020 (also known as BT.2020). Rec.709 is the standard for HDTV, Rec.2020 is the standard for Ultra-high definition (UHD), and DCI-P3 is the standard used in Digital Cinema. While there are significant overlaps among these color gamuts, each defines a distinct area within the visible color spectrum. Notably, the Rec.2020 color gamut covers the largest portion of the visible color spectrum, encompassing both Rec.709 and DCI-P3 (see Figure 3-1).

DLP Display projection optical modules produces variable white points and color temperatures. Each optical module is adjusted by the optical module manufacturer and programmed in various modes (such as cool, normal, warm) in the final product. [1].

For more information regarding color management in an optical system, refer to slides 77 - 83 of the DLP Optical Design Guidelines presentation.

Note

The brightness specification of an optical module varies depending on the white point. If color accuracy is a key requirement for the final product, specifying a target white point, such as Illuminant D65, is recommended

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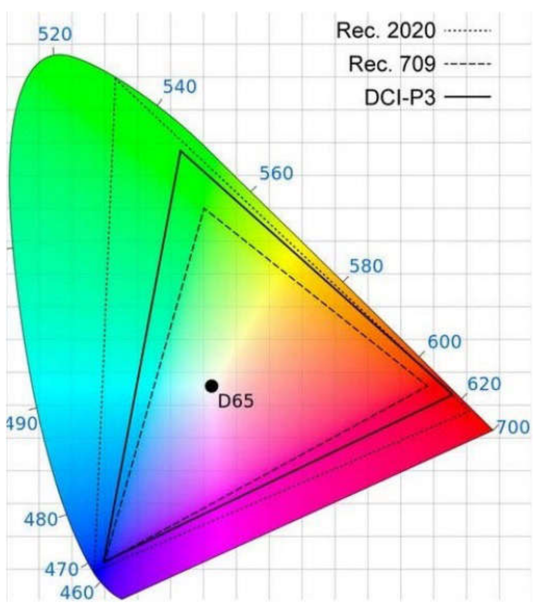

Figure 3-1. Color Gamut

[1] “ISO 11664-2:2007(E)/CIE S 014-2/E:2006,” International Commission on Illumination, http://cie.co.at/index.php?i_ca_id=484

3.4 Thermal Management

The heat sink solution provided by optical module manufacturers (such as a heat spreader or planar copper-fin heat sink) is designed to meet target brightness specification, while considering constraints such as the maximum heat load on the DMD (see data sheets), the maximum available illumination drive current, and the minimum (wall plug) efficiency of the illumination source. Based on the heat sink solution provided by the optical module manufacture, a mechanical systems engineer determines the appropriate amount of passive or active cooling (for example, a fan) required to keep the DMD and illumination source within their respective recommended operating temperature ranges. While active cooling solutions may increase power consumption and noise, active cooling solutions are more efficient at heat dissipation.

If an application does not require the maximum brightness for which an optical module is designed, the system electronics can be programmed to operate the optical module at lower power and brightness levels. In such cases, there is potential to reduce the product size by decreasing airflow requirements and collaborating with the optical module manufacture to reduce the heat sink size.

3.5 Optical Zoom

Optical zoom allows the optical module to adjust the throw ratio by mechanically repositioning a component of the projection lens. Optical zoom is commonly found in DLP Display projectors (such as Mainstream, Enterprise, and Education) and is integrable into an optical module.

3.6 Depth of Focus

The distance at which a projection lens achieves optimal focus is known as the *plane of focus*. Although focus is most precise at this plane, focus remains acceptable within a certain range both in-front and behind the plane of focus. The distance range of acceptable focus is referred to as the *depth of focus*.

DLP Display projection optical modules must be precisely focused on the target projection surface which is accomplished by adjusting the projection lens. This adjustment can be done manually, digitally with a stepper motor, or automatically using an external autofocus system (such as a camera or depth sensing system) in combination with a stepper motor.

Note

Manually focused optical modules are most common, and although autofocus options can increase costs, they simplify product setup and enhance usability for the consumer.

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4 Optical Module Specification Examples

There are two categories of optical module specifications: core and additional. Core specifications are essential for defining the performance and characteristics of the module. Additional specifications are less commonly used but can be essential for specific applications. When determining optical module requirements, it is important to carefully consider all possible specifications. Understanding the end-use of the projection system is fundamental to determining the necessary specifications of the optical module. Table 4-1 is an example of the type of questions considered by the product developer to better define the required specifications of a DLP Display projection optical module.

Table 4-1. Use Case Considerations

Use Case Considerations	Optical Module Specifications Impacted
Size of the product and space available for projection system	Size, power consumption, thermal management solution
Ambient lighting environment	Brightness, image size, DLP IntelliBright™algorithms
Battery-powered operation or plugged in to a power outlet	Brightness
Distance from the projection surface and image size target	Throw ratio
Type of video content (for example, movies, signage, PowerPoint presentations, and so forth)	Resolution, brightness, contrast ratio, color management
Projection surface shape (flat or curved)	Depth of focus
Orientation (distance, angle, position) between the optical module and the projection surface	Throw ratio, keystone correction, offset
Operating environment temperature	Thermal management solution
Maximum allowable bill of materials cost	Brightness, resolution, throw ratio

Developers can use Table 4-2 to accelerate communication with DLP Display projection optical module manufacturers. Optical module manufacturers list target and boundary specifications to effectively identify the appropriate option. The target specification should be the ideal specification, within practical constraints, while the boundary specification should define the minimum or maximum acceptable specification.

Table 4-2. Example Optical Module Specification Table

Specification	Example
Description	Provide a high level description of the application and “must-have” optical module specifications/features.
Brightness (lumens)	> 30 lumens
Resolution (x by y pixels)	854 × 480
Size (x-y-z dimensions in mm) – note if one dimension is higher priority	25mm × 25mm × 6mm (minimize thickness)
Power consumption (watts)	< 1.5W
Throw ratio	1.0:1.5
Offset (typically 0% or 100-120%)	100%
Optional Specifications	
Brightness uniformity	> 70%
Contrast ratio (full on, full off)	> 500:1
Contrast ratio (checkerboard)	> 200:1
Optical zoom (note as required or not required)	Not required
Long depth of focus (note as required or not required)	Not required
Focus method (for example manual, motorized, autofocus)	Motorized

5 Get Started with Development

Take the following steps to start product development with DLP Display technology:

1. Learn more about DLP Display technology:
    - Browse getting started resources
    - Learn about the variety of applications enabled by DLP Display technology
    - Read the Getting Started with TI DLP Display Technology application note
    - Read DLP Optical Design Guidelines for guidance on developing an optical system with DLP Products
    - Browse products and data sheets
    - Experiment with the DLP throw ratio and brightness calculator
    - Read other technical documents
2. Evaluate DLP Display technology with an easy to use Evaluation Module (EVM).
3. Download DLP Display products reference designs to speed product development, including schematics, layout files, bill of materials, and test reports.
4. Browse TI's E2E community to search for solutions, request help, share knowledge, and solve problems with fellow engineers and TI experts.
5. Find optical modules and design support using DLP Products third-party search tools.

Revision History

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