Application Report

TI DLP® Pico™ System Design: Optical Module Specifications

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ABSTRACT

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

This document focuses on projection optical modules that incorporate Texas Instruments' DLP Pico chips and are designed to project an image onto a surface for a variety of applications, including smartphones, tablets, pico 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 Pico Technology document.

Please note that the terms "optical engine" and "light engine" are also used in the projection industry. For consistency, this document will only use 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 Pico display system. It consists of five main hardware components:

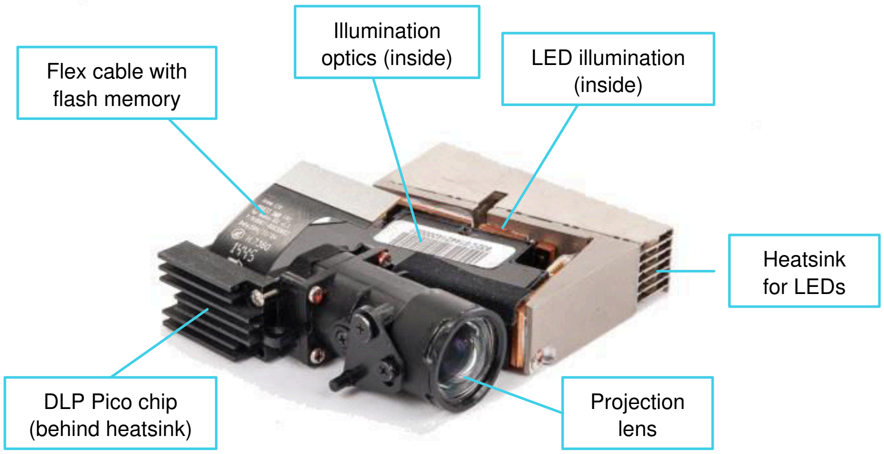


Figure 1-1. Example DLP2010 Projection Optical Module - Dimensions: 44 × 48 × 14 mm^3

1.1 DLP Pico 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.

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. Currently, most DLP Pico projection optical modules use RGB LED illumination due to its small size and high brightness efficiency. DLP Pico projection systems also use laser phosphor illumination to achieve higher brightness levels and smaller optical designs.

1.3 Ilumination Optics

Illumination optical components, such as lenses, beam mixing optics (e.g. fly's eye or light tunnel), fold mirrors, prisms, and dichroic mirrors collect light from the illumination source and guide it onto the DMD at the appropriate angle.

1.4 Projection Optics

Projection optical components collect light reflected by the DMD and project and focus the light onto a surface at some distance from the final optical component.

1.5 Flash Memory Board

The flash memory board is a small board typically attached to either the module itself 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.

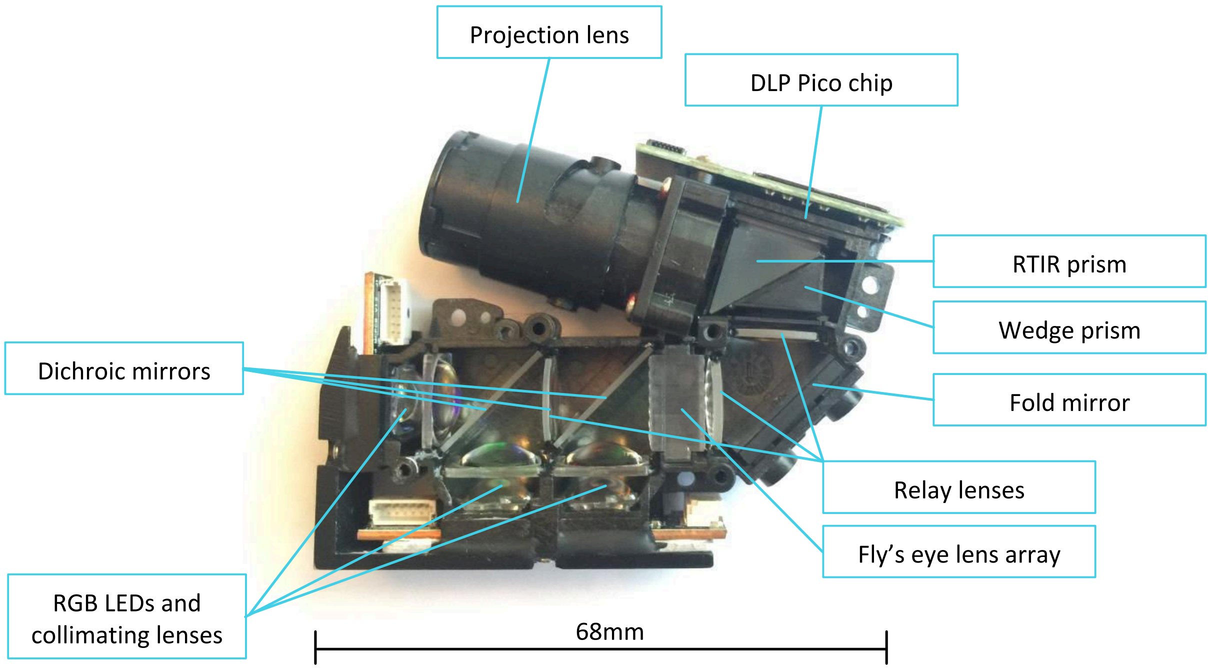


Figure 1-2. Optical Components in an Example Pico Projection Optical Module Dimensions: 68×57×15 mm^3

TI manufactures and sells the DLP chipset, which includes a DMD, a controller IC, and a power management IC (PMIC). Of these three components, only the DMD is included in an 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 (see the DLP Display & Projection Chipset Selection Guide). 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 get 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 can supply a variety of optical modules in high volumes.

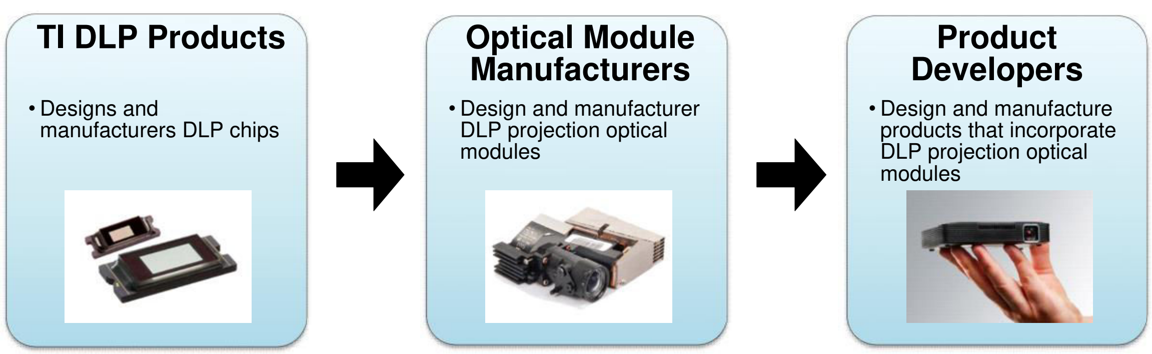


Figure 1-3. Supply Chain from TI DLP Chip to Product

2 Use Case Considerations

How the pico projection system will be used in the end product is fundamental in determining the required optical module specifications.

Table 2-1. 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

This is just a sample of the type of questions that should be answered by the product developer to better define the required specifications of a DLP Pico projection optical module.

2.1 Optical Module Specifications

It is helpful to divide optical module specifications into two categories. Core specifications are the ones most commonly used to define the performance and characteristics of an optical module. Additional specifications are less commonly used but may be critical for certain applications. It is recommended to carefully consider all possible specifications when defining optical module requirements.

3 Core Optical Module Specifications

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

3.1 Brightness

The brightness of an optical module is specified as the amount of light, in lumens, that is emitted from the projection lens when the illumination source is run at peak output and an entirely white image is displayed (that is, all DLP micromirrors are in the “on” position). All else equal, higher brightness optical modules can project images that are easier to see, particularly in brighter ambient lighting conditions, because they can create a greater difference in brightness between the projected content and the background projection surface.

Higher brightness generally comes with system tradeoffs such as larger module size and higher power consumption. These tradeoffs are mitigated by the high optical efficiency of DLP technology, which enables high brightness from small, low-power optical modules. To learn more about the brightness specification and its impact on system tradeoffs, please read the Brightness Requirements and Tradeoffs application note.

Brightness of an optical module can vary as its white point (i.e. 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.

3.2 Size

DLP Pico projection optical modules can vary in size (see Figure 3-1) and can be as small as a few cubic centimeters. The size of a DLP optical module mainly depends on three factors: DMD size (see Figure 3-2), optical design, and illumination size. In general, optical module size increases with brightness capability. Size may be specified with or without a heat sink. There is typically a heat sink on the DMD and one 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.

The performance requirements and optical design layout affect both the size and shape of an optical module. Light can be folded (that is, bounced back and forth off mirrors) to minimize a specific dimension such as depth or height. In addition, throw ratio and image offset specifications affect the size of the projection lens. A shorter throw ratio design generally results in a larger size, and a higher offset design generally results in a larger size.

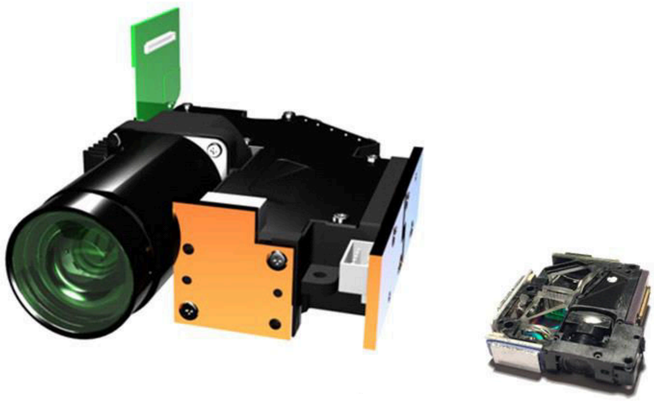


Figure 3-1. Examples of a 75-mm DLP4501 Optical Module (Left) and a 25-mm DLP2010 Optical Module (Right)

Figure 3-2. A 0.2" Diagonal DMD (e.g. DLP2010) Compared to a 0.45" Diagonal DMD (e.g. DLP4501)

3.3 Resolution

The resolution of an optical module is determined by the DMD used in the module. Higher resolution optical modules typically come with the tradeoffs of size and cost. Advancements in DLP technology continue to enable higher resolutions from smaller, lower cost optical modules.

3.4 Illumination Power Consumption

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

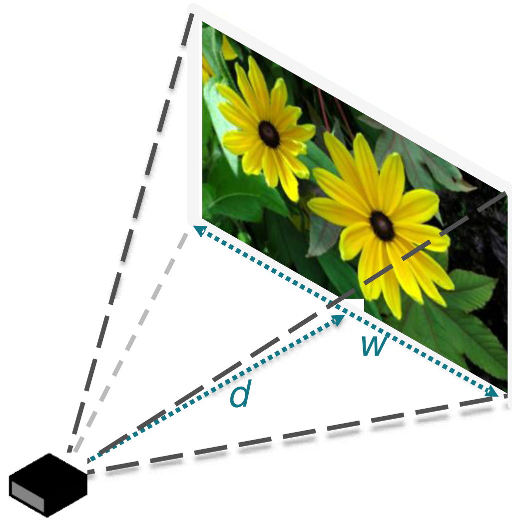
In the case of an RGB LED-illuminated optical module, the power consumption specification includes all three LEDs (red, green, and blue). The LEDs can be driven to a maximum current and temperature specified by the LED manufacturer. Total LED power consumption depends on the LED drive current as well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

3.5 Throw Ratio

Throw ratio (see Figure 3-3) describes how large of a projected image an optical module creates at a given distance from the projection surface. It 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 pico projection applications, throw ratios typically range from around 0.3 (“ultra-short”) to 2.0 (“long”). For example:

- An optical module with a throw ratio of 1.4 will create a 17” wide projected image from 24” away
- An ultra-short throw optical module with a throw ratio of 0.3 will create an 80” wide projected image from the same 24” distance

Shorter throw ratios typically result in larger projection lenses and mirrors, and therefore larger overall optical modules.



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

Figure 3-3. Throw Ratio

3.6 Offset

Offset describes the path of the projected light once it exits the projection lens. 0% offset describes an optical module that sends light equally up and down after it exits the projection lens. 100% offset describes an optical module that sends the top of the image up and keeps the bottom of the image coincident with the projection lens axis. 100% or higher (i.e. tilted up) offset 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, 0% offset may be preferred for some applications and 0% offset optical designs allow for thinner optical modules.

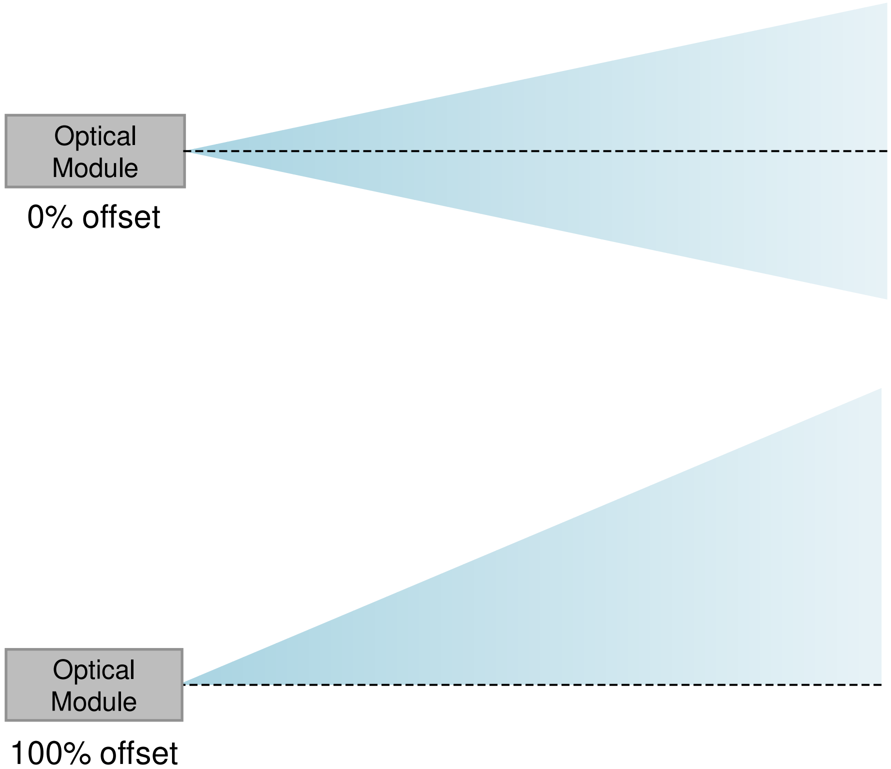


Figure 3-4. 0% Offset and 100% Offset

3.7 Contrast Ratio

There are two general methods of measuring the contrast ratio of a projection system: Full On / Full Off (FOFO) and methods using a checkerboard pattern, such as the IEC 61947 contrast standard, also known as ANSI contrast. FOFO contrast is more commonly used by optical module manufacturers.

FOFO contrast measures the ratio of the brightness of an entirely white projected image versus an entirely black projected image. The checkerboard pattern methods measure contrast using a 4 × 4 array of black and white rectangles. In both cases, the measurement is normalized as “x to 1.”

The FOFO contrast measurement is primarily impacted by the inherent contrast ratio of the DMD, whereas the checkerboard measurement is influenced by both the inherent contrast of the DMD and the contrast performance of the projection optics. As such, FOFO contrast is higher than checkerboard contrast. Checkerboard contrast is more indicative of the true contrast performance of an optical module when displaying actual video content.

Higher contrast optical modules can create more vibrant, colorful projected images while projected images from lower contrast optical modules can look washed out (see Figure 3-5).

Figure 3-5. A Simulation of a High Contrast Projected Image (Above) and a Low Contrast Projected Image (Below)

4 Additional Optical Module Specifications

The following specifications are not as frequently used to specify an optical module, but may be critically important for some applications.

4.1 Brightness Uniformity

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

$$\text{Brightness uniformity} = [(\text{lux of dimmest point}) / (\text{average lux})] / [(\text{lux of brightest point}) / (\text{average lux})] \quad (1)$$

Brightness uniformity of 100% would describe a perfectly uniform projected white image with equal brightness levels at each point. Brightness uniformity of DLP Pico projection optical modules typically ranges between 70 to 90 percent. Variation in brightness uniformity is caused by variations in optical component performance, truncation of optical elements due to size constraints, and optical misalignment. The importance of brightness uniformity depends on the application and image content being projected. For example, even relatively low brightness uniformity can be difficult to detect with typical movie or TV show content, while a solid color can make the differences in brightness more obvious.

4.2 Focus Uniformity

An ideal projection optical module has perfect focus uniformity – that is, the entire image is in focus at the same time.

If an optical module has a focus non-uniformity problem, then the image is visibly out of focus in at least one location, often the edges or corners. Focus non-uniformity can be caused by variations in optical component performance or optical misalignment.

4.3 Color Management

The color gamut of a display system defines the extent of colors that can be produced by the display. This extent is defined by the three additive primary colors: red, green, and blue. In the case of an LED-illuminated optical module, these colors are controlled by the color of the individual LEDs and any filters in the system. The color gamut is traditionally plotted in the 1931 CIE chromaticity space.

ITU-R Recommendation BT.709 (commonly known as Rec. 709) is a common HDTV color gamut recommendation created by ITU (International Telecommunications Union). It is possible for an LED-illuminated DLP projection system to achieve a wider color gamut than Rec. 709 (see Figure 4-1).

DLP Pico projection optical modules can produce variable white points and color temperatures, which can be adjusted by the optical module manufacturer and programmed into different modes (e.g. cool, normal, warm) in the final product. Note that the brightness specification of an optical module can vary depending on the white point. If color accuracy is a key requirement of the final product, it is recommended to specify a target white point, for example Illuminant D65 [1].

[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

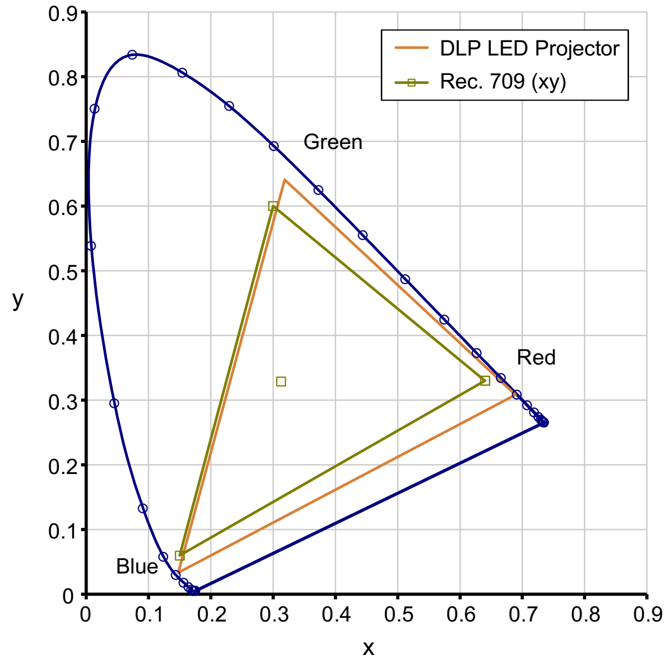


Figure 4-1. Color Gamut

4.4 Illumination Type

DLP technology can be used with any illumination type. Lamps, LEDs, and laser illumination are all potential options when designing optical modules with DLP chips. Currently, most DLP Pico projection optical modules use RGB LED illumination due to their small size and high brightness efficiency. DLP Pico projection systems also use laser illumination to achieve higher brightness levels and smaller optical designs. Optical module manufacturers can help choose an appropriate illumination type based on the system requirements.

4.5 Thermal Management

The heatsink solution provided by optical module manufacturers (for example, a heat spreader or planar copper-fin heatsink) is physically sized to achieve a target brightness specification, given the constraints of the maximum heat load on the DMD (see datasheets), the maximum available illumination drive current, and the minimum efficiency of the illumination source. Based upon the heatsink solution provided by the OMM, a mechanical systems engineer can determine 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. Using an active cooling solution can add power and audible noise, but can also dissipate more heat.

Keep in mind that if a particular application does not require the maximum brightness for which an optical module was designed, then the system electronics can be programmed to run the optical module at a lower power and brightness level. For such applications, there is also an opportunity to reduce the product size by reducing the air flow and/or working with the optical module manufacture to reduce the heatsink size.

4.6 Optical Zoom

Optical Zoom allows the optical module to change its throw ratio by mechanically moving a component of the projection lens. While this feature is not commonly found in DLP Pico projection optical modules, it can be included if necessary.

4.7 Depth of Focus

The distance at which a projection lens is focused is referred to as the “plane of focus.” While the focus is best at the plane of focus, the focus is often acceptable for some distance in front of and behind the plane of focus. This distance range over which the focus is acceptable is referred to as the “focus depth”.

A long depth of focus is generally desirable, especially for portable applications such as pico projections built in to smartphones or tablets. The longer the depth of focus, the more the product can be moved relative to the surface and still be considered in focus.

4.8 Focus Method

DLP Pico projection optical modules need to be focused at a target projection surface distance. This is accomplished by adjusting the position of the projection lens. The position can be adjusted manually, digitally using a stepper motor, or automatically using an external autofocus solution (e.g. camera or depth sensing system) in combination with a stepper motor. Currently, manually focused optical modules are most common. While autofocus solutions can add some cost, it makes the product easier to set up and use for the consumer.

4.9 Automatic White Point Correction

Over time, LED brightness can decline and change the relative mix of red, green, and blue light in the projected image. This can result in a change in the white point. To counteract this process, some optical modules include a sensor that tracks the relative brightness of each LED. This data can be used in the DLP controller to maintain a consistent white point and color temperature over time. For more information on automatic white point correction, please refer to the Real-Time Color Management for DLPC343x application note and associated reference design.

5 Features Implemented in Software

The following software features impact the performance and functionality of an optical module.

5.1 Keystone Correction

Optical modules are generally designed to be positioned orthogonal to the projection surface. When a projector is tilted relative to the projection surface, or vice versa, the image will become trapezoidal in shape due to a change in the distance between the projection lens and the edges of the projected image. To correct for this effect, some projection systems include a feature called keystone correction, which manipulates the image in software to fit it into a rectangular subset of the projected pixels (see Figure 5-1).

Keystone correction can be manually adjusted or automatic with an accelerometer which measures the tilt angle of the system. Vertical keystone correction is most common, but some projection systems also offer horizontal keystone correction. Note that keystone correction is a software feature, not a hardware feature. The DLPC343x controller has vertical keystone correction functionality for most DMDs, however for the DLP4710 chipset, keystone correction must be implemented external to the DLP controller. Consult the controller datasheet for more detailed information about how to implement keystone in your product.

Note that a shorter throw ratio optical module will result in a more distorted image when the product is tilted relative to the projection surface.

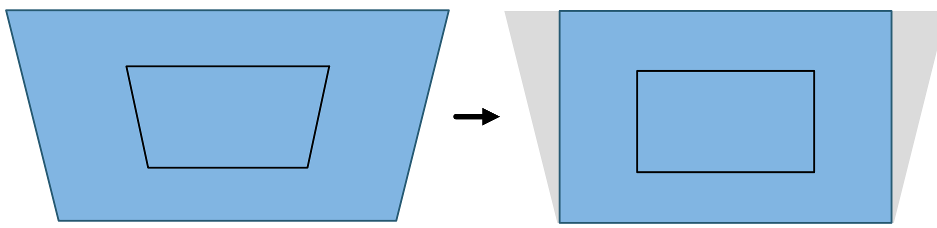


Figure 5-1. Keystone Correction

5.2 DLP Image Processing Settings

The DLP controller determines how the incoming image is displayed, through a combination of image processing techniques and control of the illumination. Image processing techniques include gamma correction, white point, color temperature, and color saturation adjustments.

Some DLP image processing settings can be defined by the optical module manufacturer, based upon design attributes of the particular optical module. To learn more about these settings, please read the DLPC343x datasheet and the DLPC343x software programmer's guide.

5.3 DLP IntelliBright™ Algorithms

DLP IntelliBright is a suite of TI image processing algorithms designed to improve the performance of LED-illuminated pico projection systems. The suite is composed of two distinct algorithms: Content Adaptive Illumination Control (CAIC) and Local Area Brightness Boost (LABB). DLP IntelliBright is a feature of DLPC343x-based chipsets.

The CAIC algorithm intelligently manages LED drive strength, on a frame by frame basis, resulting in optical image brightness and contrast. For example, if a frame has more blue than red or green, CAIC will increase the current to the blue LED. CAIC can be adjusted to maximize brightness, minimize power consumption (while maintaining the pre-CAIC brightness level), or somewhere in between with some brightness increase and some power savings.

The LABB algorithm intelligently boosts image brightness, on a frame by frame basis, resulting in brighter, more dynamic images. The LABB algorithm evaluates each image frame, in real time, first identifying dark areas of the image which can benefit from a boost in brightness, and then applying a brightness gain based on the configured "boost strength" setting. A relatively higher gain is applied to the darker regions of the image while little or no gain is applied to brighter regions of the image. LABB is particularly useful for pico projectors in high ambient lighting environments and can be automatically adjusted using an ambient light sensor.

For more details on DLP IntelliBright, please read the TI DLP IntelliBright Algorithms for the DLPC343x Controller application note.

6 Hardware Integration Considerations

6.1 Flash Memory

A flash memory PCB is typically integrated with the optical module (mounted on the exterior or on a flex cable connecting the DLP controller and DMD) and stores the firmware and configuration data (generated by DLP Composer software), and illumination calibration data (e.g. white point alignment for different image settings in a pico projector) provided by the optical module manufacture. The flash memory interfaces with the DLP controller when the optical module is integrated into a projection system.

6.2 DLP Controller to DMD Interface

The interface between the DLPC343x controller and the DMD consists of four single ended control signals and a sub-LVDS bus consisting of 4 or 8 (depending on the DMD) data pairs and a clock pair. The differential signals make up the HS (high speed) bus that sends mirror on/off data to the DMD. Three of the four control lines (LS_CLK, LS_WDATA and LS_RDATA) make up a serial control bus. While the fourth line (ARSTZ) is a power up reset.

6.3 Flash Memory to DLP Controller Interface

The DLPC34xx does not contain non-volatile memory and uses an external SPI (Serial Peripheral Bus) flash memory to hold the software image. The DLPC34xx supports 1.8 – 3.3 V devices.

7 Business Considerations

7.1 Cost

The cost of an optical module is dependent upon unit volume and is generally correlated to its performance, including brightness capability, resolution, and optical component quality.

Brightness and resolution are determined primarily by the DLP chip, illumination type and size, and optical throughput. In addition, a shorter throw ratio typically requires larger and more complex projection optics, which leads to higher cost.

7.2 Custom Optical Modules

To minimize cost and lead time, customers can leverage an existing optical module that is currently in production.

If modification of an existing optical module or design of an entirely new optical module is required, it is important to align with an OMM regarding lead times and non-recurring engineering (NRE) costs (or amortization costs associated with NRE).

Modification of an existing optical module design, such as the development of a new projection lens to enable a shorter throw ratio, is generally less costly and is quicker than developing an entirely new optical module.

7.3 Minimum Order Quantity (MOQ)

Depending upon the business opportunity, optical module manufacturers will sell optical modules in small quantities to support product development and prototyping.

For production quantities, optical module manufactures typically require minimum order quantities. The MOQ will vary from manufacturer to manufacturer.

7.4 Lead Times

Optical module manufacturers typically require lead times of 8-12 weeks or more for existing, in-production optical modules due to lead times of optical module components and manufacturing time.

8 Example Optical Module Specification Table

Developers can use this table to help accelerate communication with DLP Pico projection optical module manufacturers. By listing target and boundary specifications, the OMM will be able to more quickly identify the right solution. The target spec should be the ideal specification, within reason, and the boundary spec should be the minimum or maximum acceptable specification.

Included in the table is a column with example target specifications for a smartphone or tablet built-in pico projection application.

Table 8-1. Example Optical Module Specification Table

Specification	Priority Rank	Target	Boundary (min/max)	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				25 mm × 25 mm × 6 mm (minimize thickness)
Power consumption (watts)				< 1.5 W
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 (e.g. manual, motorized, autofocus)				Motorized

9 Get Started with Development

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

1. Learn more about DLP Pico technology:
   - Browse getting started resources
   - Learn about the variety of applications enabled by DLP Pico technology
   - Read the Getting Started with TI DLP Pico Technology application note
   - Browse products and datasheets
   - Experiment with the DLP throw ratio and brightness calculator
   - Read other technical documents
2. Evaluate DLP Pico technology with an easy to use evaluation module (EVM).
3. Download DLP Pico 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, ash for 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.

10 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (August 2017) to Revision B (September 2021)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Updated Abstract	1
• Updated and removed table from Section 1.5	3
• Updated Section 3.2	5
• Updated Section 3.3	6
• Updated Section 4.4	11
• Updated Section 4.5	11
• Updated Section 4.8	12
• Updated Section 5.1	13
• Changed steps in *Get Started with Development*	16

Changes from Revision * (February 2017) to Revision A (August 2017)	Page
• New DMD Part Number (DLP2000) and EVM (DLPDLCR2000EVM) links added to table for ultra-mobile, ultra-low power chipset class with 640 × 360 (nHD) resolution	3

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