.23” Optical Reference Design – Illumination
DLP230GP, DLP230KP, DLP230NP Chipsets

This presentation provides an optical reference design for 0.23 inch digital micromirror device, DMD, focusing on the illumination.

本报告针对0.23英寸数字微镜器件（DMD）的照明问题提出了一种光学设计参考方案。

Content

- Specs and targets
- Illumination design (optimized for 1mm×1mm LED)
- Geometric efficiency for 1mm×1mm LED
- Geometric efficiency for 1.2mm×1.5mm LED
- Summary

We will start with the DMD optical specifications and the design targets. Then the illumination design layout will be shown, which is optimized for 1 millimeter by 1 millimeter LED light source. You will be able to see the optic components, how rays pass through the system, as well as the overall optical size.

首先，我们将介绍DMD的光学技术指标和设计目标。之后，我们会给出照明系统的设计方案，该方案针对1mm×1mm的LED光源进行了优化。您将会看到具体的光学元件图、光路图以及尺寸图。

The geometric efficiency is evaluated for two popular LED sizes. The 1 millimeter by 1 millimeter LED is for high efficiency, while the 1.2 millimeter by 1.5 millimeter LED can enable high brightness.

对目前流行的两种LED尺寸的几何效率进行评估，1mm×1mm的效率较高，1.2mm×1.5mm的亮度较亮。

Specifications and targets

- Specifications:
  - # of micro mirrors: 960×540 (actuator can be added to enhance resolution)
  - Pixel pitch: 5.4 µm
  - Mirror tilt: 17 degree
  - Array size: 5.184mm by 2.916mm
  - Projection lens:
    - f/1.7 telecentric
    - Customer specific – not done in the reference design.

- Targets:
  - Compact, high-efficiency illumination
  - Provide a starting point for customer's engine design (customer to make trade-offs on performance, size, cost/manufacturability, form factor, etc.)

The DMD used in this reference design is a 960 by 540 array with pixel pitch at 5.4 micron. The angle of micromirror tilt is 17 degrees. The total active array size is 5.184 millimeter by 2.916 millimeter, with diagonal size at 0.23 inches. The same array size can have enhanced resolution with the help of an actuator. For example, the resolution can be quadrupled to 1080p with a four-way actuator.

在本参考设计中使用是960×540分辨率阵列、像素间距5.4µm的DMD；其微镜倾角为17°，总有源阵列尺寸为5.184mm×2.916mm，对角线长0.23寸。使用驱动器的情况下，相同的阵列尺寸可以获得更高的分辨率。例如：使用四路驱动器，可以把分辨率提升四倍至1080p。

The projection lens is highly customer specific and not covered in this reference design. However, we need to specify it to be f/1.7 and telecentric in order to match the illumination design.

投影镜头由用户自行设计，不包含在本设计方案内，但为了匹配照明方案，其应设计为f/1.7的远心镜头。

The target of the reference design is to achieve compact and high efficiency illumination. And the reference design is to provide a starting point for customer's engine design. Based on the reference design, customers can make trade-offs on performance, cost, form factors, et cetera.

我们的设计目标是结构紧凑且照明效率高。本参考方案的出发点是提供一个光机雏形设计，基于它用户可以在性能、成本和外观尺寸等方面进行权衡。

DMD (Digital Micromirror Devices) etendue and LED matching

- DMD capability:
  - Width direction: 5.184×sin(17deg) ×cos(34deg) = 1.257mm
  - Height direction: 2.916×sin(17deg) = 0.853mm

- LED of choice (near 0.853mm×1.257mm):
  - 1mm×1mm LED for high efficiency and compact size
  - 1.2mm×1.5mm LED for high brightness (efficiency will be compromised)

TEXAS INSTRUMENTS

Before we dive into the design, let's look at the DMD etendue capability, and see what size of LED would be a good match. The DMD etendue is determined by the active array size, as well as the cone angle collectible to the projection lens. We assume f/1.7 projection lens, which corresponds to plus or minus 17 degree cone angle.

在我们深入研究设计之前，让我们先看一下DMD的光学扩展量能力，以及与之匹配最佳的LED尺寸。DMD光学扩展量由有源阵列的尺寸和投影镜头的收束角决定。我们不妨假定投影镜头的光圈为f/1.7，其对应于±17°锥角。

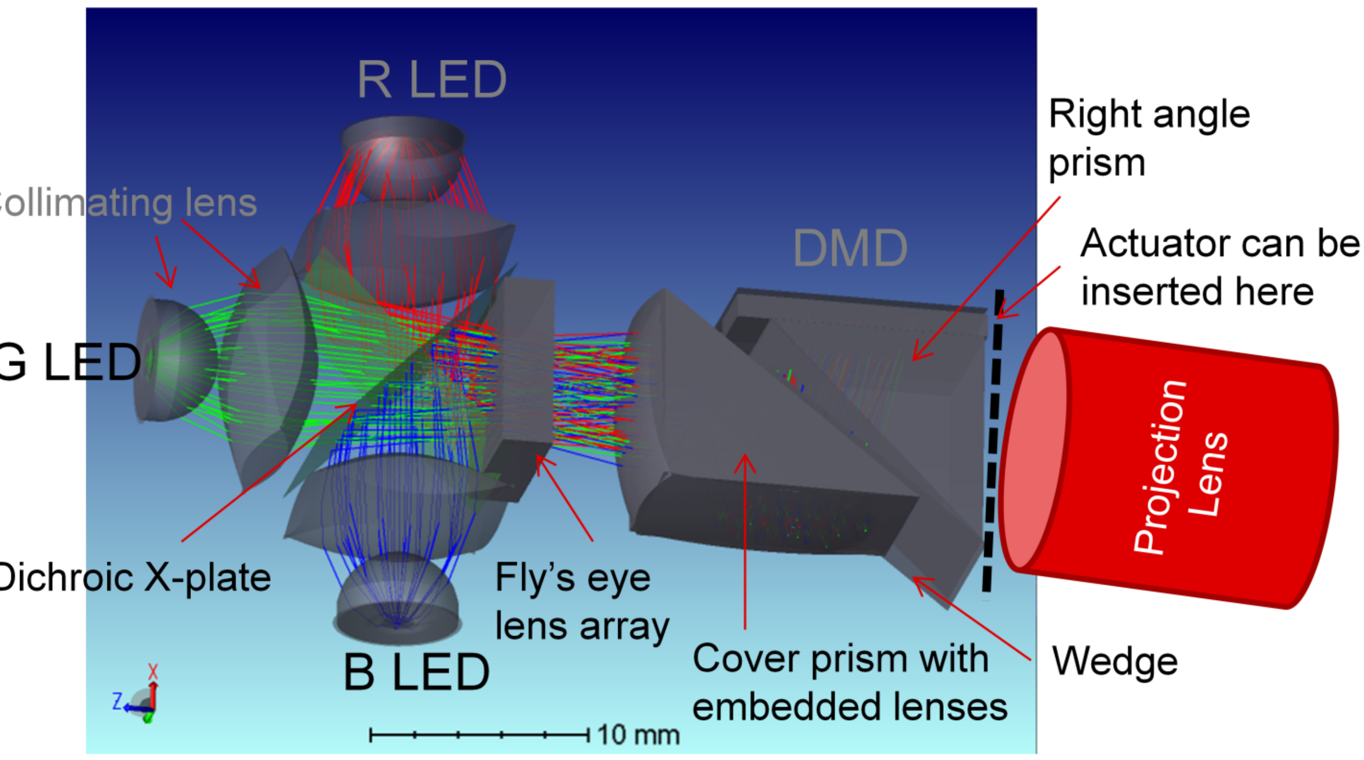
The calculation can be separated along width and height directions, where the size times the sine of the cone angle would preferably match the size of a Lambertian emitting LED, which has emitting cone angle of plus-minus 90 degrees. Notice this is a side illuminated DMD, where the illumination direction is along DMD width direction at around 34 degrees. So the width direction, we'll need to add a cosine factor to it. As a result, we calculate the DMD is capable of matching to a 1.257 millimeter by a 0.853 millimeter Lambertian emitting LED.

计算分成宽度和高度两个方向进行。在每个方向上，DMD的相应尺寸与锥角正弦的乘积，应恰好与朗伯LED光源（其锥角为±90°）的尺寸相同。注意到DMD此时是侧向照明的，其中照明方向与DMD宽度方向约34°。所以在宽度方向，我们需要添加一个余弦因子。因此，我们计算出与DMD匹配的朗伯LED光源尺寸为0.853mm×1.257mm。

Two popular LED sizes near this are chosen, with 1 millimeter by 1 millimeter LED can have high efficiency, while the 1.2 millimeter by 1.5 millimeter LED can have high brightness with compromised efficiency.

因此，有两种通用的LED尺寸可供选用：1mm×1mm照明效率很高；1.2mm×1.5mm亮度高但效率不如前者。

Illumination optics



- In-line configuration:
  - Compact
  - P-lens flexible
  - Actuator insertion easier
- X-plate:
  - High geometric efficiency
  - Space saving

This picture shows the optical layout of the illumination design. Light sources are RGB LEDs that have the same emitting size. Light from each LED is collected and collimated by two lenses. After collimation, RGB colors are combined to a common path by a dichroic X-plate. Following the X-plate is a Fly's eye lens array, which is to homogenize the light to create uniform illumination on DMD. The X-plate enables both high efficiency and space saving.

此图为照明设计的光学布局。光源是三个具有相同发光尺寸的LED，其颜色分别为R、G、B。来自每个LED的光被两个透镜汇聚并准直。准直后，三基色光通过二向色性X形平板进行合束。继X形平板之后是一个复眼透镜阵列，它确保了光线均匀照射到DMD上，实现均匀照明。X形平板的使用，同时保证了高照明效率和高空间利用率。

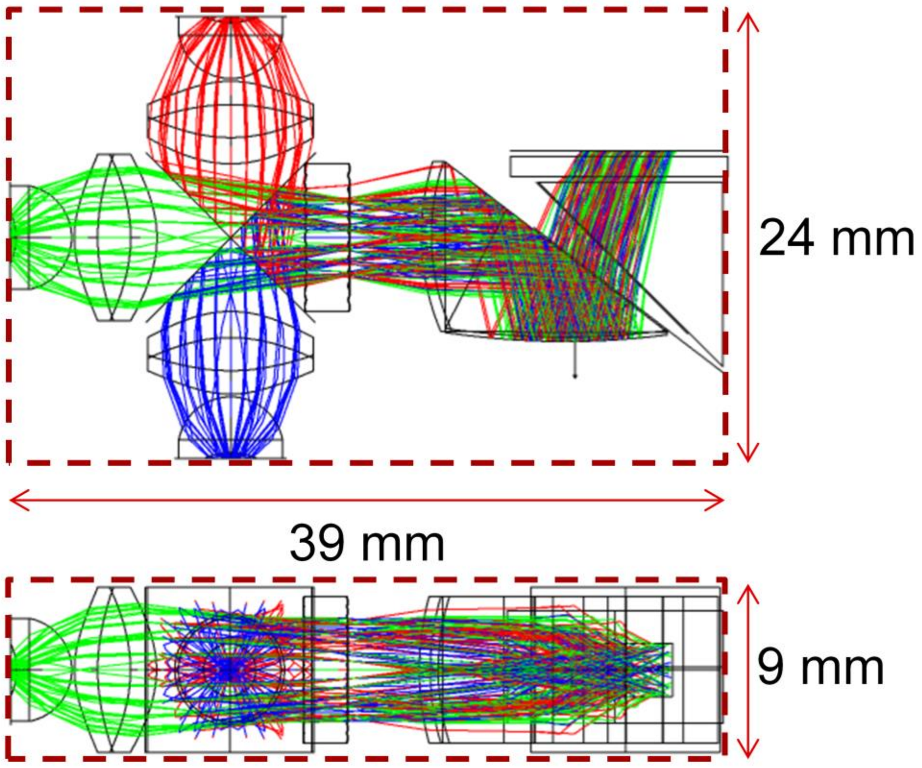
After the lens array, is a plastic cover prism that has curved surfaces molded on two sides. One curved surface is transmissive, and the other is reflective. Together with the flat surface, and the following wedge, and the right angle prism; they create a uniform sharp image on the DMD as illumination. The light reflected by the DMD will be directed to the projection lens by the right angle prism, so total internal reflection, TIR.

在复眼透镜阵列之后，有一个塑料棱镜，它有两个曲面，一个是透射式的一个是反射式的。该棱镜连同它的平面镜面、以及其后的光楔与直角棱镜，共同为DMD提供照明，产生均匀清晰的图像，最终DMD的反射光经直角棱镜的反射，进入投影镜头。自此，所有发生的反射均为全内反射。

The combination of the reflective cover prism, the wedge, and the right angle prism forms an inline configuration. This configuration not only enables compact size, but also folds the illumination to the opposite side of the projection lens, allowing enough space to accommodate large-sized projection lenses, such as ultra-short throw lens. The open space also makes the insertion of an actuator easier when considering enhancing the resolution.

反射棱镜，光楔和直角棱镜的组合构成了同轴布局。这种布局不仅使结构紧凑，而且将光源移动到了投影镜头的对侧，从而预留了足够的空间去容纳大尺寸投影镜头（如：超短焦镜头）。这种开放的空间还可以很方便灵活地插入驱动器，以提高投影分辨率。

Illumination size (optical)

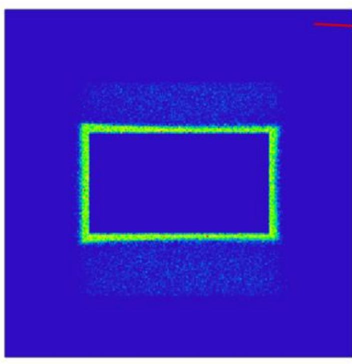


- The size is optimized for 1mm×1mm LED.
- Engine can be used for larger 1.2mm×1.5mm LED for higher brightness.

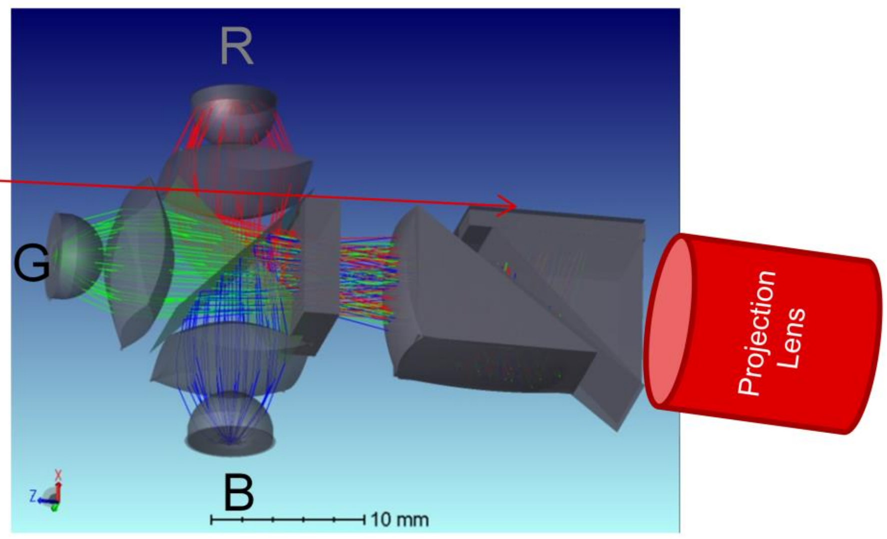
The two views on this page show the optical size of the illumination, 39 millimeter by 24 millimeter, with 9 millimeter height. To estimate the final engine size, well we need to add the other necessary mechanical and electrical components. Again, the size is optimized to achieve high efficiency for 1 millimeter by 1 millimeter LED. You can be directed to use the for 1.2 millimeter by 1.5 millimeter LED with compromised performance.

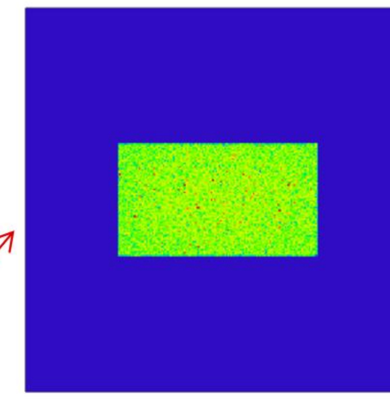
此页面上的两个视图显示了照明的光学尺寸：长宽39mm×24mm，高度9mm。若要估计最终光机成品的尺寸，我们还需添加其他必要的机械和电气部件。再次强调，以上尺寸是针对1mm×1mm的LED光源的照明效率进行优化的，若使用1.2mm×1.5mm的LED则会使其性能下降。

Geometric efficiency for 1mm×1mm LED



17.04% G overfill on DMD





71.94% G on screen

- Green (1mm×1mm LED): 71.94%;
- Red (1mm×1mm LED): 70.69%;
- Blue (1mm×1mm LED): 71.0%

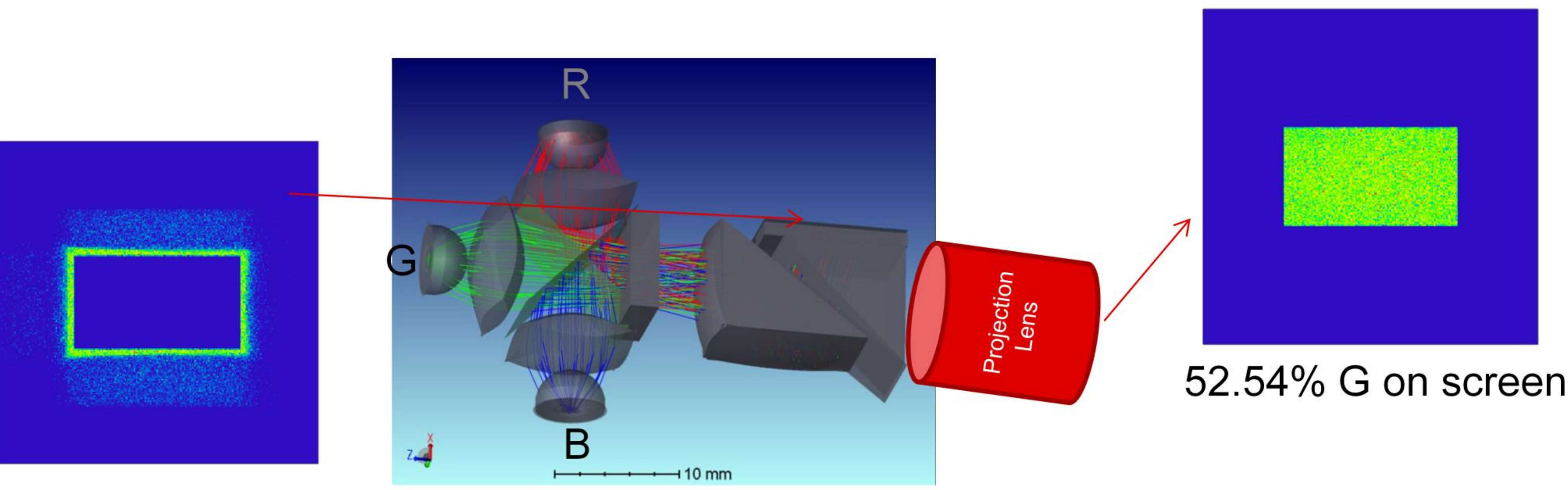
This page shows the evaluation result of the design using 1 millimeter by 1 millimeter LED. Geometric efficiency is a key performance metric that characterizes the percentage of the total rays passing through the optical system. It does not take into consideration of diffraction loss, surface reflection loss, material absorption loss, et cetera. However, with the geometric efficiency, customer can use their transmissive data together with the DMD efficiency to estimate the engine efficiency.

本页展示了使用了1mm×1mm的LED光源的仿真结果。这里使用的几何效率，是一种表征通过光学系统的光量与总入射光量比值的重要性能指标。尽管几何效率不考虑衍射、表面反射和材料吸收等损耗，但用户仍然可以通过它和DMD的工作效率，估计光机的工作效率。

By adding in the LED optical output, we can estimate the total lumen output of the engine. We will also need to allow for reasonable overfill on DMD to accommodate the alignment error, due to various tolerances. We can see after the overfill loss, the design achieved high geometric efficiency at around the 71% across all LEDs.

在加入LED光源后，我们可以仿真得到光机的总光通量输出。由于各种设计公差，我们设置了一定量的光通量冗余以补偿各种对准误差。我们可以看到在考虑到冗余损耗后，本设计方案仍然能确保高达71%的几何效率。

Geometric efficiency for 1.2mm×1.5mm LED



17.39% G overfill on DMD

- Green (1.2mm×1.5mm LED): 52.54%;
- Red (1.2mm×1.5mm LED): 52.30%;
- Blue (1.2mm×1.5mm LED): 51.14%

Brightness vs. 1mm² LED: 1.2×1.5×0.52/0.71 = 1.31X

We noticed the efficiency is at the screen, what we assumed, an ideal f/1.7 telecentric projection lens. If we use 1.2 millimeter by 1.5 millimeter LED on the same optics, we can see the efficiency drops to around 52%. But due to the LED emitting area is almost twice as big and twice as bright, the total brightness will be significantly higher than the engine width 1 millimeter by 1 millimeter LED.

图中我们假定使用的是理想的f/1.7远心投影镜头。若在同一光学系统中换作1.2mm×1.5mm的LED，我们可以看到效率会下降到52%左右。但由于LED的发光面积与亮度都几乎是原先的两倍，故光机的总输出亮度明显高于之前。

Summary

- An optical reference design is provided for the illumination of .23” DMD (960×540 micro mirrors), targeting small size and high efficiency.
- Geometric efficiency is evaluated for 1mm×1mm LED and 1.2mm×1.5mm LED, assuming LED Lambertian emission, and f/1.7 telecentric projection lens.
- The reference design is to provide a starting point for customer’s engine design. Customers can optimize their design based on the trade-offs of performance, size, cost/manufacturability, form factor, etc.

In summary, we provided an optical reference design for the illumination of 0.23 inch 17 degree tilt DMD, targeting small size and high efficiency for 1 millimeter by 1 millimeter LED. Assuming an f/1.7 telecentric projection lens, high geometric efficiency is achieved at 71%. The efficiency for 1.2 millimeter by 1.5 millimeter LED is also evaluated, and the result shows higher brightness can be achieved by this larger LED.

现在做一下总结。我们提供了一种光学参考设计，适用于0.23寸17°倾斜DMD的照明问题，使用了1mm×1mm的LED，有尺寸小和效率高的特点。使用f/1.7远心投影镜头的情况下，系统的几何效率高达71%。我们也估计了使用了1.2mm×1.5mm的LED后的效率，结果表明尺寸更大的LED可以使亮度更高。

Again, this reference design is to provide a starting point for customers' engine design, based on which designers can make their own trade-offs between performance, size, cost, et cetera. Thank you for your attention.

该参考设计旨在为用户产品的光机设计提供一个雏形，设计人员可以此为基础，在性能、尺寸和成本等方面进行权衡。感谢观看。