

Application Report

Dynamic Ground Projection Application Requirements



Jackson Thomas

ABSTRACT

Custom lighting and illumination has been a distinguishing feature in automobiles of all segments for decades, but until recently this was limited to LED color schemes or static logos. With the automotive qualification of TI DLP® Technology, automotive manufacturers and Tier 1's now have the ability to create personalized content with dynamically changing logos or videos in full color with dynamic ground projection (DGP). Small projectors can be embedded in door panels, side mirrors, rocker panels, front and rear bumpers, and many more locations throughout the car to project full-motion video on the ground surrounding the vehicle. While these dynamic ground projectors use the same display technology as many cinema and pico projectors, the image quality and brightness requirements can differ from traditional display applications, as well as between locations in the vehicle. This application report discusses the brightness, power, and image quality requirements for dynamic ground projectors in various automotive applications.

Table of Contents

1 Static projection in automotive applications	2
2 Brightness Requirements	2
2.1 Main Parameters that Influence Display Brightness.....	2
2.2 Other Brightness Considerations.....	4
2.3 Brightness Capabilities with DLP Technology.....	6
3 Summary	6
4 References	7

List of Figures

Figure 2-1. Brightness at different times of day.....	5
Figure 2-2. DGP projections with varying contrast.....	5

List of Tables

Table 2-1. Typical Ambient Illumination Levels.....	2
Table 2-2. Average Reflectance of typical materials.....	3
Table 2-3. Typical projector capabilities for the DLP3021-Q1.....	6

Trademarks

DLP® is a registered trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

1 Static projection in automotive applications

There are several examples of automotive implementations of static projector applications, from door panel logo projectors producing small images and rocker panel projection along the length of the car, to general welcome lighting projected around the vehicle. There are also countless aftermarket implementations available. These previous implementations help set the expectations and requirements for future implementations with dynamic content.

2 Brightness Requirements

Projectors for automotive applications can have varying optical flux requirements, around 100 lumens for some augmented reality head-up display systems and over 1500 lumens for some high resolution headlight systems. Dynamic ground projector (DGP) applications also have varying flux requirements, but will typically be below 50 lumens. The main parameter that determines the required brightness in a DGP application is display size, but there are also several parameters that might restrict maximum brightness such as required mechanical form factor, required power limit, ambient brightness, or desired thermal performance.

There are two main units used to determine the brightness of a projector or a display. The optical flux of a projector is typically measured in lumens (lm), a measurement of the total light output of the projector, while the brightness, or luminance, of a display is typically measured in candela per meters squared (cd/m^2), or nits. The relationship between luminance [cd/m^2], illuminance [lux], and optical flux [lumens] are described in the equations below.

2.1 Main Parameters that Influence Display Brightness

Ultimately, the brightness of the displayed image is all the end user, driver or passenger, will see in a DGP implementation. The projector flux, displayed image size, surface the image is displayed on, and ambient lighting conditions will all determine the overall perceived brightness of the displayed image.

2.1.1 Ambient Lighting Conditions

For an image to be visible, the image brightness must be greater than the natural or ambient brightness of the surface onto which the image is being projected, where the natural brightness depends on both the amount of ambient illumination and the surface reflectance. The ratio of image brightness relative to the natural projection surface brightness is called the luminance contrast ratio (LCR). An image is typically just-visible when the LCR is 1.5, meaning the image is 50% brighter than the surrounding surface. However "just-visible" is typically insufficient from the perspective of usability. To be usable, a minimum LCR of 2-4 is often required. For maximum usability (across a range of ambient conditions), an LCR of 25 or more is desirable

The brightness of the ground will depend on the ambient lighting conditions and surface reflectivity in the area. A well-lit city street directly under a street light will have much more light reflecting off of it than a country back road illuminated only by the moon. To maintain the same LCR, the displayed image must be much brighter in well illuminated conditions than in dark ones. Typically, a display with a higher LCR is desirable and the image will never appear too bright in DGP applications. Dynamic ground projectors should be designed to be visible in the brightest nighttime ambient conditions, and darker conditions will only improve the perceived brightness of the displayed image. Daytime brightness conditions are prohibitively bright for DGP applications to be visible.

The approximate ambient brightness levels in various lighting conditions are included in [Table 2-1](#).

Table 2-1. Typical Ambient Illumination Levels

Night Lighting Condition	Typical Ambient Illumination (lux)
Twilight	10.8
Full Moon	0.108
Starlight	0.0011

2.1.2 Projection Surface Impact on Display Brightness

The measured and perceived brightness of an image also depends heavily on the surface upon which it is projected. Projection display screens are often a reflective white color that may even have some gain built in to

redirect more of the light towards the viewer to make the image appear brighter. Most surfaces not engineered for displays (for example, concrete) will be lambertian which means any light reflected off the surface will be scattered equally in all directions so the apparent brightness of the surface appears the same from all angles. The color, texture, and material itself can greatly affect the perceived brightness of the DGP image. The brightness of the image on different surfaces can be determined by the material reflectivity, along with the projector flux and image size. The reflectivity for several typical ground surfaces can be found in the table below, but these may change significantly based on specific composition along with many other environmental factors.

Table 2-2. Average Reflectance of typical materials

Surface Type	Average Reflectivity
Cement	0.47
Asphalt	0.15
Grass	0.20
Gravel	0.29
Dirt	0.15

The conversion between illuminance (lux) to luminance (cd/m²) is relatively simple for a lambertian surface. Most pavement and ground surfaces are assumed to be lambertian.

$$\text{Luminance} \left[\frac{\text{cd}}{\text{m}^2} \right] = \frac{\text{Illuminance} [\text{lux}]}{\pi} \times \text{Reflectivity} \quad (1)$$

2.1.3 Size of the Displayed Image

For a particular projector with a fixed throw ratio (ratio of projection distance to image width), the farther away from the display surface the projector is located, the larger the displayed image becomes. But for a constant optical flux, as the image becomes larger, it also gets dimmer as the projected light spreads over the larger image. If the image becomes too dim, it is no longer recognizable by the viewer. For projection applications in a vehicle, throw ratio and projector location parameters will likely be fixed by design. This ensures the image is the desired size and focuses properly, and will set the brightness of the image.

Projected image brightness is inversely proportional to displayed image area. If the displayed image area doubles, the brightness will decrease by 50%. For this reason, a small projected image from a side mirror will require a lower brightness projector than a rocker panel projector creating an image along the length of the car because the size of the two images are typically very different. The side mirror mounted projector may only require 10 lumens while the rocker panel mounted projector may require 80 lumens.

2.1.4 Brightness of the Displayed Image

The estimated brightness of a DGP image can be calculated with the numbers provided in the previous sections. Combining image size, projection surface, ambient conditions, and projected lumens will give the brightness of the projected image, and this can be used to predict how visible the image will be in various ambient lighting conditions.

$$\frac{\text{Projector Flux} [\text{lm}] \times \text{Reflectivity}}{\text{Image Size} [\text{m}^2] \times \pi} = \text{Image Brightness} \left[\frac{\text{cd}}{\text{m}^2} \right] \quad (2)$$

$$\text{LCR} = \frac{(\text{Image Brightness} + \text{Ambient Brightness})}{\text{Ambient Brightness}} \quad (3)$$

Rearranging the above equations to solve for required projector flux (in lumens) as a function of LCR, ambient brightness, image size, and surface reflectivity, the equation becomes the following.

$$\text{Projector Flux [l m]} = \frac{\text{Ambient Brightness} \left[\frac{\text{c d}}{\text{m}^2} \right] \times (\text{LCR} - 1) \times \text{Image Size} [\text{m}^2] \times \pi}{\text{Reflectivity}} \quad (4)$$

As an example, assume the ambient lighting condition of asphalt is 10 lux (approximate illuminance during twilight) and the desired image is 0.09 m² (~18" diagonal) and has an LCR of 25. Using [Equation 1](#), the 10 lux ambient illuminance on asphalt gives an ambient luminance of

$$\frac{10 [\text{lux}]}{\pi} \times 0.15 = 0.48 \left[\frac{\text{c d}}{\text{m}^2} \right] \quad (5)$$

Using [Equation 4](#) and these ambient conditions, the minimum required projector brightness is

$$\frac{0.48 \left[\frac{\text{c d}}{\text{m}^2} \right] \times (25 - 1) \times 0.09 [\text{m}^2] \times \pi}{0.15} = 21.6 [\text{l m}] \quad (6)$$

For a large logo or animation projection (~18") displayed on asphalt at twilight with high visibility (LCR of 25) the DGP projector would need to output slightly more than 20 lumens. This is a feasible brightness for a projector based on the DLP3021-Q1 automotive grade DMD.

2.2 Other Brightness Considerations

There are many other parameters that less directly affect the visibility of the image or cannot be fully controlled by the design of the projector. Below are a few more considerations when determining the brightness requirements for a DGP application.

2.2.1 Time of Day

The time of day will have a tremendous effect on visibility of the image. This is really just a change in the ambient brightness value in the equations above, so it will also affect projector brightness requirements. Viewing a DGP image (or any projected image) in full sun will require tremendous brightness from the projector. Brightness requirements this high, likely between 500 and 1000 lm, would increase cost, size, complexity, and thermal load of the projector, making it a challenge for low cost DGP applications.

While full sun viewing may not be feasible, small increases in brightness could allow for modest visibility of the image in dusk or twilight hours, rather than just full night time conditions. By modifying the ambient brightness variable in the above equations, projector brightness for evening operation can be estimated. The images in [Figure 2-1](#) were taken in August in Dallas, Texas, and are representative of a high brightness time of year at different times of the day.



Figure 2-1. Brightness at different times of day

2.2.2 Projector Contrast

The contrast of a projector (or any display) is the ratio of brightness in a full-white image to a full-black image. Ideally displays would have infinite contrast, where any black pixel displayed emits no light, but in practice this doesn't happen. If a displayed contrast is too low, not as much detail can be seen in darker parts of the image. For a projected image with low contrast in a high ambient brightness environment, a dark border can sometimes be seen around the image, illuminating a grey box, or 'postcard' around the bright image in the center.



Figure 2-2. DGP projections with varying contrast

For DGP applications, the ambient lighting conditions will not be well controlled, so the contrast needs to be high enough to avoid making the background visible in dark ambient conditions. But overdesigning the contrast can lead to increased cost and size. Projectors for DGP applications should be designed for a contrast that will provide good enough performance while minimizing manufacturing cost. What contrast level is deemed 'good enough' is subjective and will also depend on the projection surface. Typically this is around 400:1 contrast as a minimum. 400:1 contrast in many dark ambient conditions will still be high enough to remove the background shadow from the image.

2.2.3 Other Application Constraints

Several other factors will indirectly influence the maximum brightness of a DGP projector. Many applications will have module size and input power limitations. Higher brightness projectors will require more input power. Some placements in the vehicle may limit the total power available to deliver to the module, limiting the maximum brightness of the projector. Higher power or larger LEDs will also increase brightness, but this will also typically increase the required thermal cooling solution. If this thermal solution makes the module size too large, the

brightness may need to be reduced to accommodate the size constraint. If power or thermal constraints limit brightness, the size of the displayed image may need to be reduced in order to achieve desired brightness targets.

2.3 Brightness Capabilities with DLP Technology

After determining the required minimum flux of a projector for DGP applications, the output capabilities of a particular projector should be evaluated. While there are many different factors that determine the final output brightness and module size of a projector design, [Table 2-3](#) has some general output targets for example configurations using the DLP3021-Q1 automotive qualified DMD for full color DGP applications. Actual size and output flux will vary depending on individual designs.

Table 2-3. Typical projector capabilities for the DLP3021-Q1

Electrical Input Power (W)	Output Flux (lumens)	Approximate Projector Size (mm)
3	up to 25	50 x 30 x 25
10	up to 120	80 x 80 x 30

3 Summary

The ultimate success of a DGP application depends on being clearly visible to the driver or pedestrian. Many different factors affect the apparent brightness of a dynamic ground projection display including projector brightness, ambient lighting conditions, and projection surface. Different requirements for image size and placement may cause different requirements for projector brightness, contrast, and overall form factor. Understanding the desired viewing conditions and display content is the first step to determining the remainder of the DGP brightness design.

4 References

For more information on dynamic ground projection applications, see the following resources

- Texas Instruments, [DLP3021-Q1 Product Folder](#)
- Texas Instruments, [DLP3021-Q1 0.3-Inch WVGA DMD Data Sheet](#)
- Texas Instruments, [DLP3021-Q1 FPGA User guide](#)
- References for reflectivity of different road materials:
 - [Recommended Light Levels \(Illuminance\) for Outdoor and Indoor Venues](#)
 - [HOMER Pro 3.14 Ground Reflectance](#)
 - [Average Ground Reflectance Info](#)
 - [Experimental Analysis of Natural Gravel Covering as Cool Roofing and Cool Pagement](#)
 - [Remote Sensing for Soil Science](#)

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2022, Texas Instruments Incorporated