Application Report

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TI DLP® Pico™ Technology for Aftermarket Head-up Displays

Vivek Thakur and John Ferri

ABSTRACT

Advances in consumer display technology present the opportunity to equip any automobile with aftermarket head-up display (AM-HUD) solutions. The objective of this application report is to help product developers design aftermarket head-up displays incorporating Texas Instruments DLP® Pico™ technology.

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Trademarks

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1 Introduction

A head-up display (HUD) is a transparent display that superimposes rich, configurable, real-time data in a driver's normal line of sight. The HUD concept first appeared in military aircraft, where it was increasingly necessary for the pilot to be able to monitor critical flight data without looking away from outside the aircraft to an instrument panel within the aircraft. As the capabilities of HUDs improved and dropped in price, HUDs found widespread application in commercial and even private aviation. In recent years, HUDs began appearing as a factory installed option in many high-end automobiles.

Recent advances in consumer display technology present the opportunity to equip any automobile with an aftermarket head-up display (AM-HUD) solution. The same powerful technology behind DLP Pico products can be used in the automobile for high-brightness, interactive display systems that enhance the driving experience. The small size, low power, economical cost, and proven reliability of DLP Pico technology provides the foundation for compelling AM-HUD products.

DLP Products offers a wide variety of digital micromirror devices (DMDs), including chips specifically designed for consumer, industrial, and automotive applications. Regardless of which DMD is selected, appropriate considerations should be made to meet the recommended operation conditions specified in the device datasheet. This document will explain key design requirements and trade-offs for aftermarket head-up display solutions based on DLP Pico technology.

2 Applicable Documents

The following TI Documents contain relevant information:

- Getting Started with DLP Pico Technology
- DLPC343X display controller datasheets: DLPC3430, DLPC3433, DLPC3435, DLPC3438 and DLPC3439.
- PMIC datasheets: DLPA2000, DLPA2005, DLPA3000 and DLPA3005
- DMD datasheets: DLP2010, DLP3010 and DLP4710
- Optical module manufacturers
- Application Note: Geometric Optics for DLP

Always refer to the latest revision of datasheets.

3 Terminology

3.1 Types of AM-HUD

There are several implementations of aftermarket HUD products. These different design approaches are broadly classified into the following categories:

Projector HUD

A Projector HUD creates an image on a diffuser screen with no additional optics after the projector (Figure 1).

Figure 1. Projector HUD

Teleprompter HUD

A Teleprompter HUD allows indirect viewing of an image through partial reflection from the car's windshield, or a partially reflective screen in front of the windshield (Figure 2).

Figure 2. Teleprompter HUD

Augmented HUD

An augmented HUD uses mirror optics to create a virtual image floating beyond the windshield (Figure 3).

Figure 3. Augmented HUD

This document focuses on augmented HUD technology for AM-HUD applications.

3.2 HUD Terminology

Figure 4 and Figure 5 illustrate the terminology used in this document.

Head-up Display (HUD)

A transparent display that presents data in the driver's normal line of sight by creating a virtual image.

Augmented Reality (AR)

Superimposes a computer-generated image on a user's view of the real world, thus providing a composite view.

Virtual Image (VI)

An image that appears to “float” at some focal distance in space.

Virtual Image Distance (VID)

The focal distance where the virtual image appears to reside. The apparent distance between the viewer’s eyes and the virtual image created by the HUD optics. Typically, the virtual image is created well beyond the windshield of the car.

Field of View (FOV)

The angle subtended at the driver’s eyes by the virtual image presented by the HUD.

Horizontal Field of View (HFOV)

The horizontal angle (along x-axis) subtended from the driver’s eyes to the virtual image.

Vertical Field of View (VFOV)

The vertical angle (along y-axis) subtended from the driver’s eyes to the virtual image.

Combiner

A partially reflective element of the optical chain that reflects light towards the viewer and allows outside light to pass through.

Eyebox

The area in which the HUD virtual image is viewable by the driver.

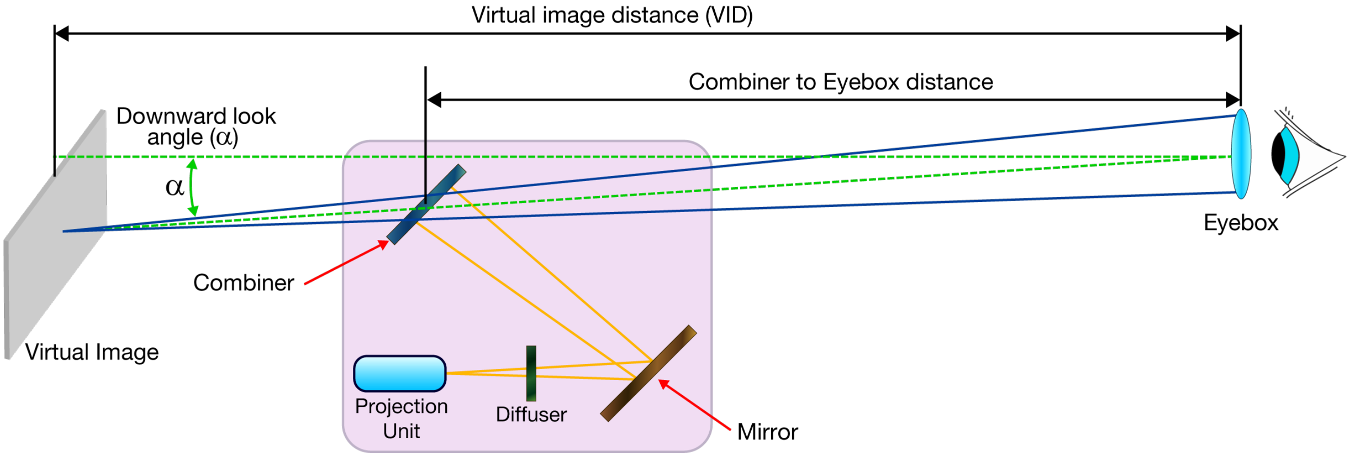


Figure 4. HUD Diagram

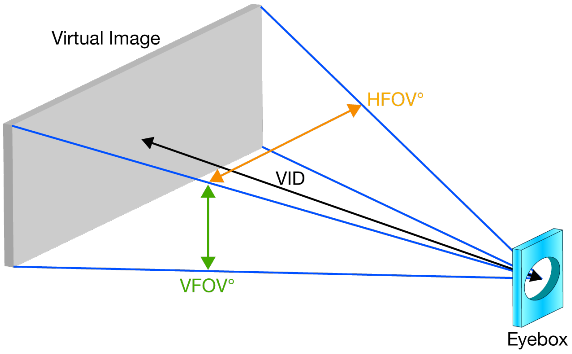


Figure 5. HUD Eyebox and Field of View

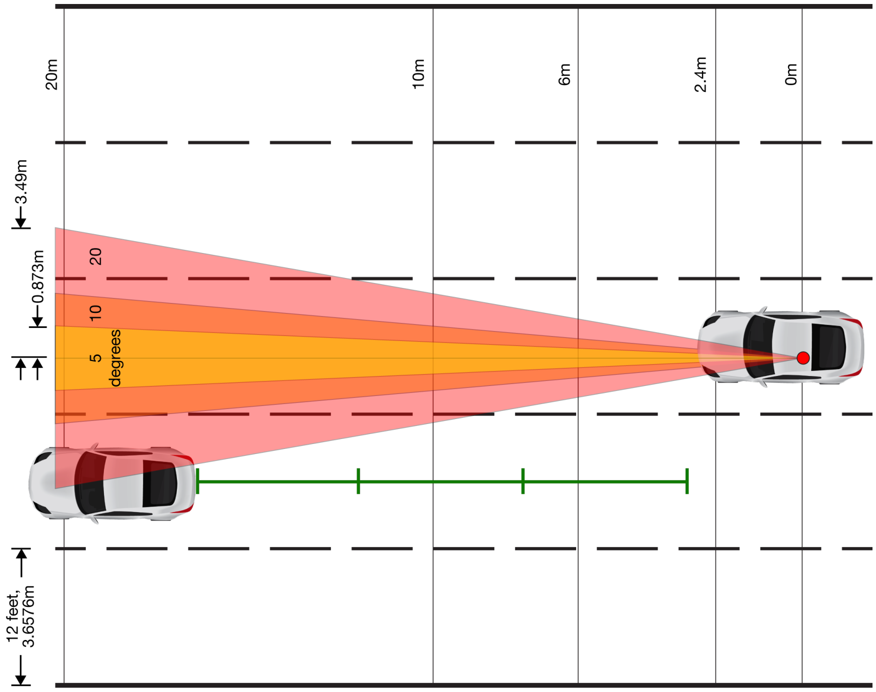
4 AM-HUD Key Requirements

4.1 Field of View

The field of view (FOV) (Figure 6) is an important specification of an AM-HUD system. A wider field of view is desirable so that all required and useful information can be displayed without clutter, and in a way which is easily read by the driver. At the same time, the FOV should not be so wide that the driver is distracted from monitoring their car's current lane in the road. Ideally, the virtual image should be contained within the car's current lane width at a reasonable distance ahead.

Typically, lanes of US highways are 3.7 meters wide. A virtual image with a 12° FOV will span across a 3.7 meter lane at a distance of nearly 18 meters in front of the driver. The preferred horizontal field of view (HFOV) is between 6° to 12°, and a vertical field of view (VFOV) between 3° to 6°.

The total light output required from the HUD projection unit increases with FOV, so the increased power demand of a wider FOV should be taken into consideration.



Horizontal FOV : 6° to 12°
Vertical FOV : 3° to 6°

Figure 6. Field of View (FOV)

4.2 Resolution

The resolution of a display determines the sharpness of the virtual image seen by the viewer (Figure 7). Resolution is determined by the combination of the FOV and the pixel density of the display. A typical human eye resolves about 1 arcminute per pixel. That means that a person with 20/20 vision can resolve a maximum of 60 pixels in a 1° FOV. A WVGA (854 x 480) resolution DLP chipset enables up to a 14° HFOV in which the viewer will be unable to discern the individual pixels in the virtual image.

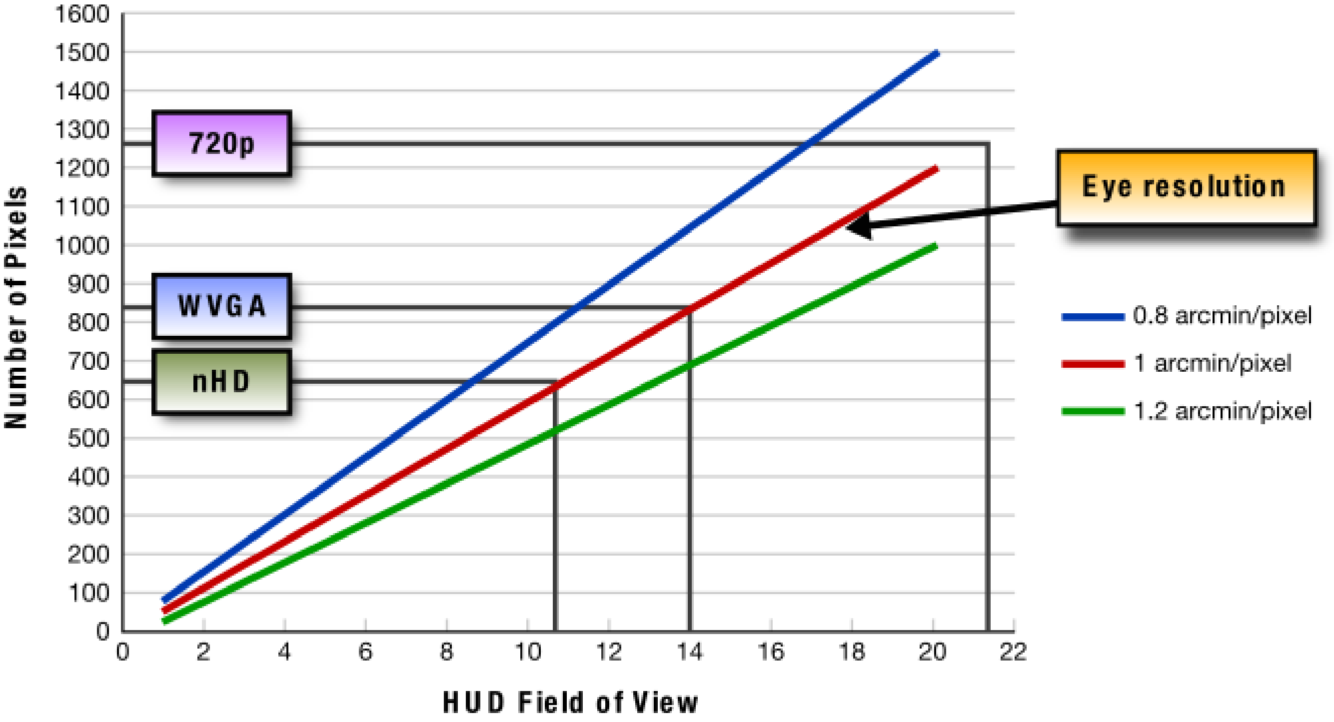


Figure 7. Number of Pixels Required Per FOV

4.3 Virtual Image Distance

The desired virtual image distance (VID) is typically within the range of 2.4 meters to 30 meters (8 ft to 98 ft) so that the HUD presents information at the normal sight distance of vision during driving. A 3° down angle is also recommended for the virtual image so that the driver does not have to move their attention away from the lane of traffic in order to see information. The VID has no impact on the total light output from the projection unit, or the resolution required for the HUD. The virtual image position is determined by the HUD optical design.

4.4 Eyebox

The HUD “eyebox” (1) is a region within which the full virtual image can be viewed with at least one eye. A typical suggested eyebox dimension for AM-HUD is 140 mm x 60 mm. An AM-HUD offers more flexibility in the vertical dimension of the eyebox because the driver is able to adjust the vertical position of the eyebox, either by adjusting the tilt angle of the combiner, or the tilt of the entire HUD unit.

Interpupillary distance (IPD) is the distance between the center of the pupils of the two eyes. IPD is critical for the design of HUD systems, where both eyes’ pupils need to be positioned within the eyebox.

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(1) In optical systems, the eyebox is sometimes referred to as the exit pupil.

Table 1 gives a list of the IPD values for each gender from 1988 Anthropometric Survey of U.S. Army Personnel databases.

Table 1. Interpupillary Distance (IPD) for Both Genders[1]

Gender	Sample Size	Mean (mm)	Standard Deviation	Minimum (mm)	Maximum (mm)
Male	1771	64.7	3.7	52	78
Female	2205	62.3	3.6	52	76

[1] *1988 Anthropometric Survey of U.S. Army Personnel*

A relatively small head movement (> 1.5 inch / 40 mm lateral) will cause one eye to be outside of the eyebox. The optical design of the HUD should ensure that, under these conditions, the other eye can see the complete image. The performance evaluation points of an eyebox are highlighted by dots in Figure 8.

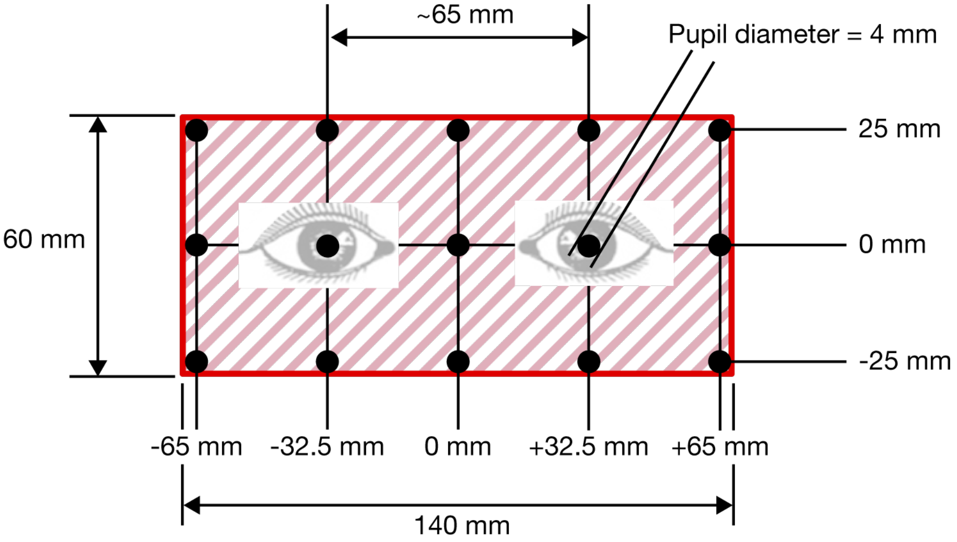

Figure 8. Eyebox and Evaluation Point

4.5 *Image Brightness*

An AM-HUD needs to support a wide range of image brightness levels. During a bright sunny day, an image with 10,000 - 15,000 nits may be required. At night or during darkness (*e.g.* driving through a tunnel), 50 to 100 nits may be adequate. The brightness of an LED-illuminated DLP projection system can be easily adjusted by modulating the LED current intensity. LED current intensity is a software programmable feature in the DLP chipset, and can be changed during operation.

5 AM-HUD System

The system block diagram of an AM-HUD is shown in Figure 9. A standard optical engine incorporating DLP Pico projection display technology can be used for AM-HUD. A customer can make necessary system level trade-offs to leverage a wide range of optical engines available from suppliers and not require a custom development.

The projector incorporating DLP technology projects an image on the diffuser screen. A combination of mirror(s) and combiner create a virtual image in front of the viewer's eyes, as shown in Figure 10. Normally the fold mirror(s) is a flat mirror, and the combiner is a free-form plastic with 20-25% reflectivity. Since the FOV is relatively small, one can use a diffuser screen with very high gain. This reduces the total light output required from the projection unit. A diffuser screen with 20× gain is recommended for AM-HUD applications.

The diffuser screen (in this example a transmissive screen) and one fold mirror can be replaced with a single "reflective diffuser" screen. This may help reduce the overall size of the AM-HUD product.

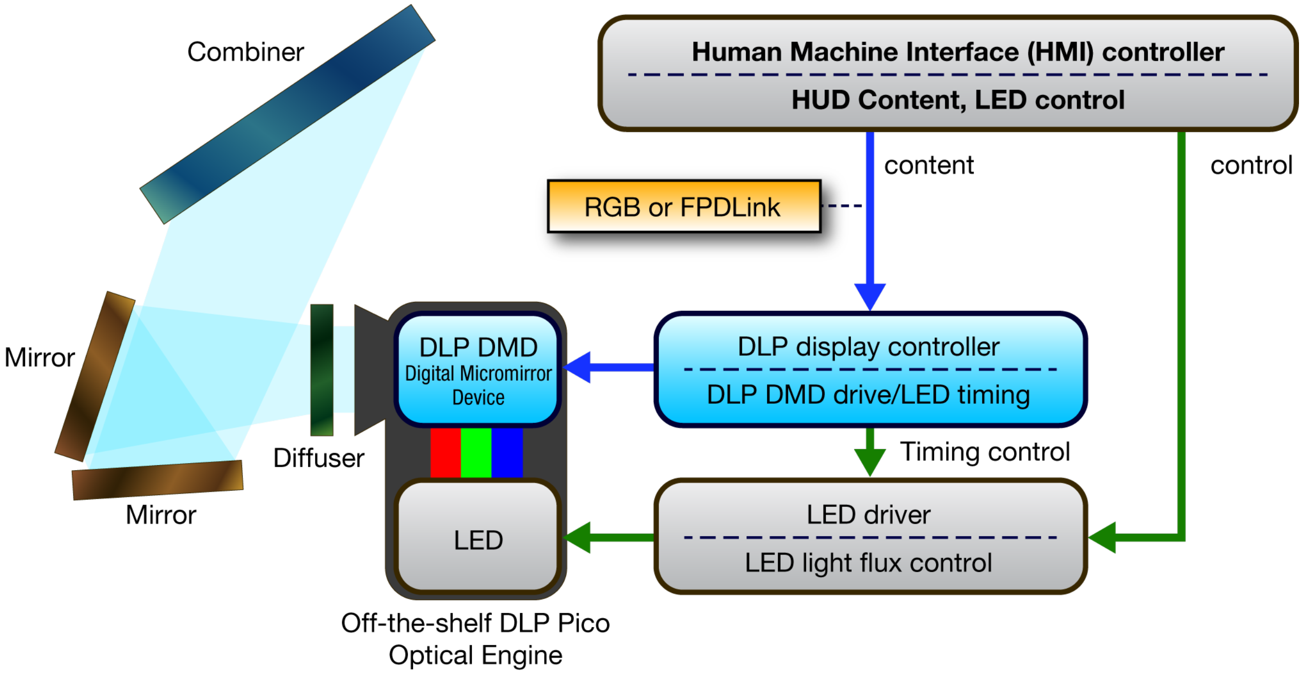

Figure 9. DLP AM-HUD System Simplified Block Diagram

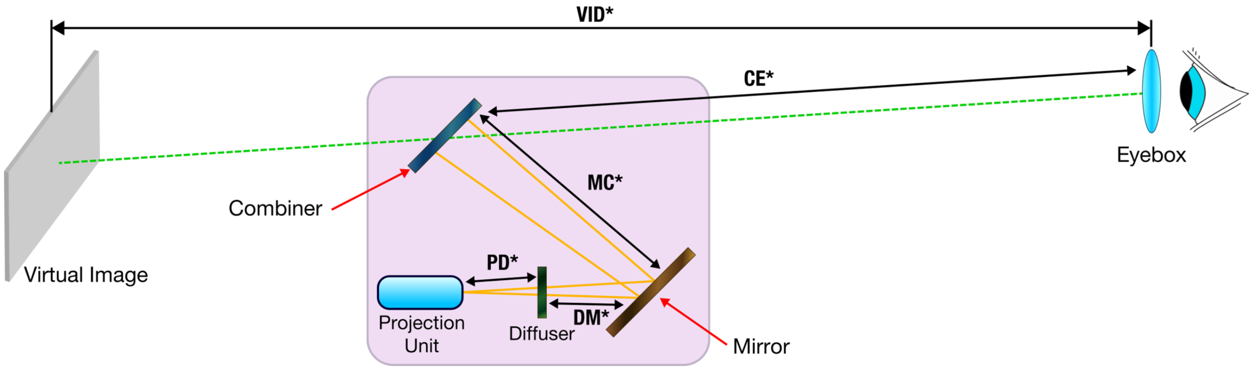

Figure 10. Virtual Image

* These variables are defined in Table 3.

6 AM-HUD System Design Trade-Offs

In this section we will use the following specifications to discuss AM-HUD system design trade-offs.

Table 2. Typical AM-HUD Specifications

Features		Values
Image Brightness intensity		15,000 nits or cd/m^2
Virtual Image Distance		2,000 cm
Distance between Combiner and Eyebox		75 cm
Eyebox size		140mm x 60mm
Field of View	Horizontal	12°
	Vertical	6°
Panel Resolution		WVGA (854x 480 Pixel)

6.1 Light Output vs. Eyebox and Field of View

The total light output (lumens) required to create the virtual image at the eyebox depends on the desired maximum brightness intensity of the virtual image, the area of the eyebox, and the FOV.

As stated before, virtual image distance (VID) has no impact on the total light required, even though the virtual image size grows with VID for a given FOV.

The following formula provides an approximation of the total light (lumens) required for a rectangular eyebox:

$$\text{Total\_Light} = 4 \times EyeBox_{\text{x}} \times EyeBox_{\text{y}} \times Brightness_{\text{intensity}} \times \tan\left(\frac{1}{2} \cdot HFOV\right) \times \tan\left(\frac{1}{2} \cdot VFOV\right)$$

Where

Total_Light — Total light at pupil in lumens

EyeBox$_X$ — X dimension of eyebox in meters

EyeBox$_Y$ — Y dimension of eyebox in meters

Brightness$_{\text{intensity}}$ — Maximum brightness intensity of virtual image in nits or cd/m^2 (typically 10,000 nits to 15,000 nits)

HFOV — Horizontal field of view

VFOV — Vertical field of view

Estimated total light (reflected to driver's eyebox) for

140 mm × 60 mm eyebox, 12° × 6° FOV and max virtual image brightness 15,000 nits ≈ 2.78 lumens

6.2 Combiner and Diffuser Specification

Refer to Figure 10 for assumptions.

The values are chosen to design a compact size AM-HUD and typical use case.

Table 3. Combiner and Diffuser Specification

Description	Variable	Values
Distance from projection unit to diffuser screen	PD	To be calculated[(1)]
Distance between diffuser screen and fold mirror	DM	5 cm
Distance between fold mirror and combiner	MC	15 cm
Combiner to eyebox distance	CE	75 cm
Virtual image distance	VID	2,000 cm

(1) Will match the throw ratio of the projector.

6.2.1 Diffuser Screen Dimensions

The following equation can be used to estimate the size of the diffuser screen:

$$\text{Diffuser Width} = \frac{\{2 \times VID \times (DM + MC) \times \tan\left(\frac{1}{2} \cdot HFOV\right)\}}{(VID - CE)}$$

$$\text{Diffuser Height} = \frac{\{2 \times VID \times (DM + MC) \times \tan\left(\frac{1}{2} \cdot VFOV\right)\}}{(VID - CE)}$$

Diffuser dimensions for reference design:

$$\text{Width} = \frac{\{2 \times VID \times (DM + MC) \times \tan\left(\frac{1}{2} \cdot HFOV\right)\}}{(VID - CE)}$$

$$\text{Width} = \frac{\{2 \times 20,000 \times (50 + 150) \times \tan\left(\frac{1}{2} \cdot 12^\circ\right)\}}{(20,000 - 750)}\text{mm}$$

$$\text{Width} = 44\,\text{mm}$$

$$\text{Height} = \frac{\{2 \times VID \times (DM + MC) \times \tan\left(\frac{1}{2} \cdot VFOV\right)\}}{(VID - CE)}$$

$$\text{Height} = \frac{\{2 \times 20,000 \times (50 + 150) \times \tan\left(\frac{1}{2} \cdot 6^\circ\right)\}}{(20,000 - 750)}\text{mm}$$

$$\text{Height} = 22\,\text{mm}$$

$$\text{Diffuser Size} = 44 \times 22mm$$

6.2.2 Combiner Specification

The combiner optical element can be made using injection molded plastic lens technology. It should be coated for 20-25% reflectivity.

There are two optical design choices for combiner and fold mirrors:

- Option 1 — The combiner is a free-form surface, with the fold mirror as a plane (flat) mirror.
- Option 2 — The combiner is a spherical surface, with the fold mirror as a free-form surface for the appropriate optical correction.

The following expressions can be used to estimate size of the combiner:

$$\text{Combiner Width} = 2 \times CE \times \tan\left(\frac{1}{2} \cdot HFOV\right) + \text{EyeBox}_x \times \left(1 - \frac{CE}{VID}\right)$$

$$\text{Combiner Height} = 2 \times CE \times \tan\left(\frac{1}{2} \cdot VFOV\right) + \text{EyeBox}_y \times \left(1 - \frac{CE}{VID}\right)$$

Combiner dimensions for reference design:

$$\text{Width} = 2 \times CE \times \tan\left(\frac{1}{2} \cdot HFOV\right) + \text{EyeBox}_x \times \left(1 - \frac{CE}{VID}\right)$$

$$\text{Width} = 2 \times 750 \times \tan\left(\frac{1}{2} \cdot 12^\circ\right) + 140 \times \left(1 - \frac{750}{20,000}\right) \text{mm}$$

$$\text{Width} = 292\,\text{mm}$$

$$\text{Height} = 2 \times CE \times \tan\left(\frac{1}{2} \cdot VFOV\right) + \text{EyeBox}_y \times \left(1 - \frac{CE}{VID}\right)$$

$$\text{Height} = 2 \times 750 \times \tan\left(\frac{1}{2} \cdot 6^\circ\right) + 60 \times \left(1 - \frac{750}{20,000}\right) \text{mm}$$

$$\text{Height} = 136\,\text{mm}$$

$$\text{Combiner size} = 292 \times 136\,\text{mm}$$

The optical specifications of the combiner will be a free-form surface. It will depend on the material and manufacturing process.

6.3 Projection Unit Specification

An existing DLP projection engine can be used in an AM-HUD design. The key specifications for projection units are brightness, throw ratio, resolution and minimum focus distance. In this section, these values are calculated.

Brightness

The total light output from a projector is measured in lumens. The following factors need to be considered in estimating the required light output from the projector:

- Combiner reflectivity ~ 20%
- Diffuser transmission efficiency ~ 90%
- The diffuser's light scatter is normally larger than the eyebox. Only approximately 40-50% of light reaches the eyebox.
- Imaging Area Utilization

The aspect ratio of the HUD image in this example is 12:6 and the suggested DLP panel (WVGA) has an aspect ratio of 16:9. The resulting HUD image is formed by a subset of the panel's available area, according to the following equation:

$$\frac{VFOV/HFOV}{DMD\,aspect\,ratio}$$

$$\frac{\left(\frac{6}{12}\right)}{\left(\frac{9}{16}\right)} = 89\%$$

$$\text{Total required light at eyebox} = 3.17\,\text{lumens}$$

$$\begin{gathered}\text{Required projection unit brightness}\\ = 2.78 \times (1/0.20) \times (1/0.90) \times (1/0.40) \times (1/0.89)\\ \approx 45\,\text{lumens}\end{gathered}$$

Throw Ratio

The following equations can be used to calculate distance between projection unit and combiner:

$$\frac{1}{f} = \frac{1}{DM + MC} - \frac{1}{VID - CE}$$

$$\frac{1}{\text{ProjectorDistance}} = \frac{1}{f} - \frac{1}{CE}$$

Substituting values into the first equation:

$$\frac{1}{f} = \frac{1}{2,000} - \frac{1}{19,250}$$

$$f = 202.1\,\text{mm}$$

Substituting values into the second equation:

$$\frac{1}{\text{ProjectorDistance}} = \frac{1}{202.1} - \frac{1}{750}$$

$$\text{ProjectorDistance} = 277\,\text{mm}$$

$$\text{Distance between projector and diffuser screen} = 277 - 200 = 77\,\text{mm}$$

$$\text{Projector Throw ratio} = \frac{\text{Distance}}{\text{Diffuser width}} = \frac{77}{44} = 1.74$$

Projection unit specification is shown in Table 4:

Table 4. Projection Unit Specification

Features	Values
Brightness	~45 lumens
Resolution	WVGA (854x480)
Minimum focus distance	77 mm
Throw ratio	~1.74

7 Electronic System

Figure 11 illustrates a typical block diagram for a DLP Pico projection system. The drive electronics consist of a DLP controller (DLPC3430/35) and a power management IC (DLPA2005). The DLP controller supports both parallel and DSI interface for connectivity to a processor. The DMD device (DLP2010) is integrated into the optical engine along with the LED illumination unit.

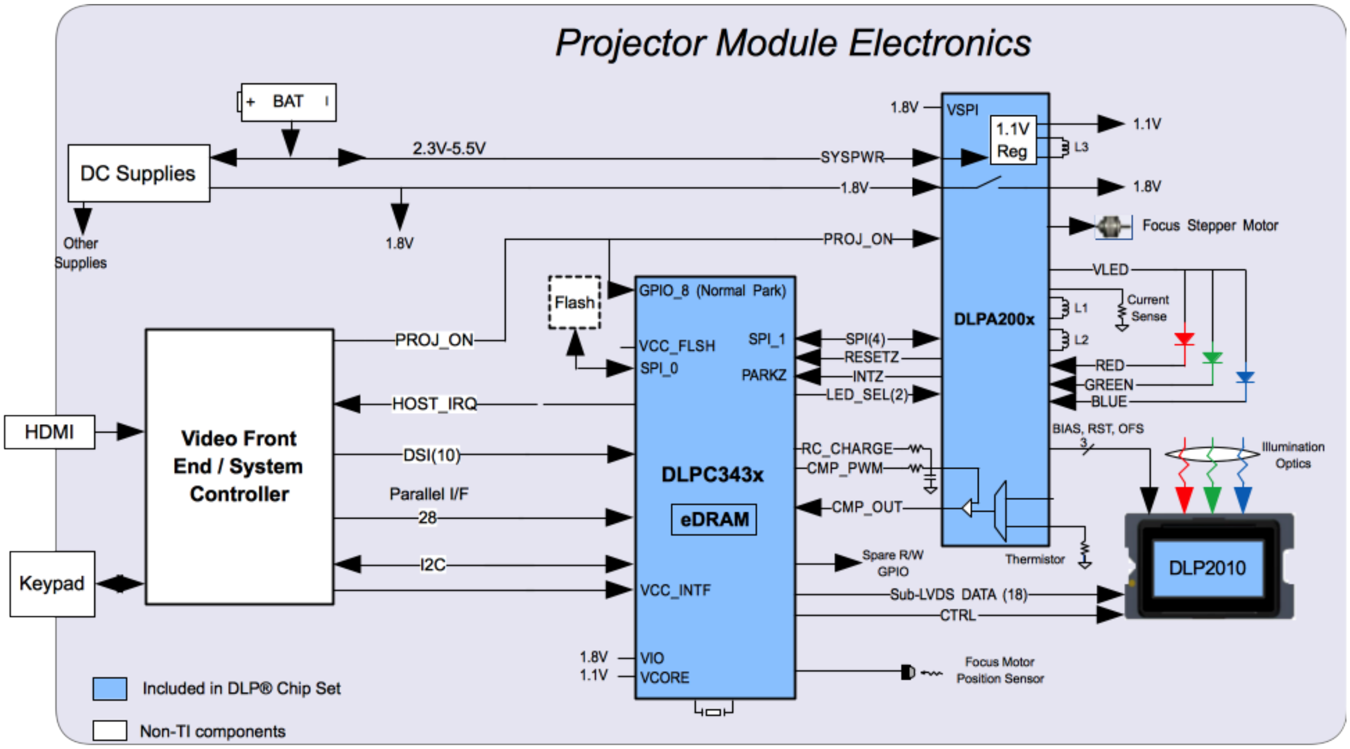

Figure 11. Typical DLP AM-HUD System Block Diagram

8 Conclusions and Getting Started

DLP technology can enable a wide field of view in a compact and small form factor aftermarket HUD system. The high optical efficiency of DLP Pico technology facilitates bright, vivid images and low power consumption. Furthermore, the high contrast ratio of DLP technology creates an excellent transparent see-through image without any gray background.

To get started with DLP Pico technology, we recommend the following actions:

- Learn more about DLP Pico technology.
  - Read the Getting Started with TI DLP Pico Technology white paper.
  - Browse DLP products and datasheets.
  - Experiment with the DLP throw ratio and brightness calculator.
- Evaluate DLP Pico technology with an easy to use evaluation module (EVM).
- Download TI Designs reference designs to speed product development, including schematics, layout files, bill of materials, and test reports.
  - DLP2010: Ultra Mobile, Ultra Low Power Display Reference Design using DLP Technology
  - DLP3010: Portable, Low Power HD Projection Display using DLP Technology
- Find optical modules and design support.
  - Buy TI DLP Pico optical modules.
  - Contact optical module manufacturers for high volume, production-ready optical modules.
  - Contact DLP design houses for custom solutions.
- Contact your local TI sales representative or TI distributor representative.
- Check out TI's E2E community to search for solutions, get help, share knowledge and solve problems with fellow engineers and TI experts.

Revision History

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

Changes from Original (September 2016) to A Revision **Page**

- Corrected eyebox dimension from 160 mm × 60 mm to 140mm × 60mm and brightness from 3.17 to 2.78 lumens in estimated total light equation in Section 6.1 10
- Corrected equation from 'Width' to 'Height' and changed Eyebox y value from 140 to 60 in combiner dimensions for reference design in Section 6.2.2 12
- Corrected equation values from 3.17 to 2.78 and 50 lumens to 45 lumens in Section 6.3 13
- Corrected Brightness value from ~50 lumens to ~45 lumens in Table 4 14

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