Introduction to automotive augmented reality head-up displays using TI DLP® technology

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Augmented reality (AR) head-up displays (HUDs) are the next evolution toward creating a better driving experience.

Based on real-time sensor data, key information such as advanced driver assistance system (ADAS) alerts and navigational cues are projected into the driver's field of view, interacting with and marking real world objects. Unlike traditional HUDs, graphics are projected further out, appearing as natural extensions of the driver's field of view. By placing graphics directly in the driver's line of sight that interact with and augment real world objects, AR HUDs can significantly improve driver situational awareness.

Traditional versus AR HUDs

Today's automotive HUDs have small displays with basic graphic functionality. The projected HUD graphics are typically located 2-3 m in front of the driver, which places the image near the car's front bumper. This location is referred to as the virtual image distance (VID). A horizontal and vertical field of view (FOV) specified in degrees defines the display size. The eyebox of the HUD is the area in which the driver is able to view the entire display, and can be limited in today's HUDs. An example showing the eyebox in relation to the virtual image is shown in **Figure 1**. Today's HUDs provide a secondary display for information that is already available in other areas of the vehicle. The graphics are mostly static and do not interact with the real world as seen from the driver's point of view. Examples of secondary information displayed on today's HUDs include the speedometer and navigational symbols, which also appear on the cluster and center stack of the vehicle.

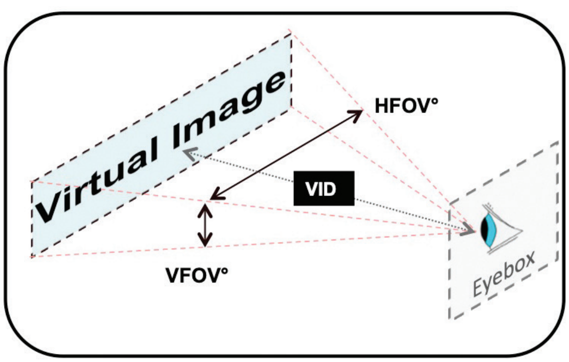


Figure 1. *FOV and VID in a HUD*

There are several limitations with today's HUDs. Their small FOV limits the way information can be displayed and how much of the real world the HUD symbols can interact with. The short VIDs do not support overlaying graphics onto real-world objects due to the way the human eye perceives distance. Additionally, today's HUDs do not take advantage of vehicle sensor data to create real-time human machine interfaces (HMIs) that interact with the driver's FOV.

Benefits of AR HUDs

Instead of showing secondary static information, AR HUDs can display graphics that interact with the driver's FOV, overlaying critical information directly onto the real world. This, of course, requires the integration of a vast amount of real-time vehicle sensor data, which is no easy task. But think for a moment about how this type of display will change the driver's experience.

Figure 2. Future (AR) HUDs will allow for a FOV of 10 degrees or more and overlay graphics directly onto the real world

Today, ADAS alerts are primarily indicated via a blinking symbol or an audible alarm. But an AR HUD can identify threats by directly marking them within the driver's FOV. AR graphics are overlaid onto real world objects in such a way that the driver can immediately recognize the threat and quickly take appropriate action, such as braking for a road obstacle. Presenting ADAS alerts in this manner could significantly increase driver situational awareness, especially when driving at night or in low visibility conditions.

One of the central requirements for an AR HUD is the ability to project images at least 7 m in front of the driver, with 10 to 20 m preferable. Projecting images at this distance creates the illusion that the images are fused with the real world; the images look like a natural extension of the object being highlighted. The human vision system has several ways in which it perceives distance or depth, but at 7 m or further, the ability to distinguish depth from the other real-world objects diminishes greatly. Creating images that fuse with the real world is only one advantage of a longer VID. The other advantage is the reduction in eye accommodation time, which becomes more significant with age.

Projecting the images further out greatly reduces the accommodation time for the eyes to adjust between the real world and the HUD images. In a non-AR HUD, with the graphics projected 2 m to 3 m away from the driver, there is an accommodation delay when changing focus between the graphics and the real world. When displaying ADAS information on an AR HUD with a long VID, the driver can more quickly react to the threat and take the appropriate action.

True augmented real functionality

Requires VID > 7m and FOV>10°

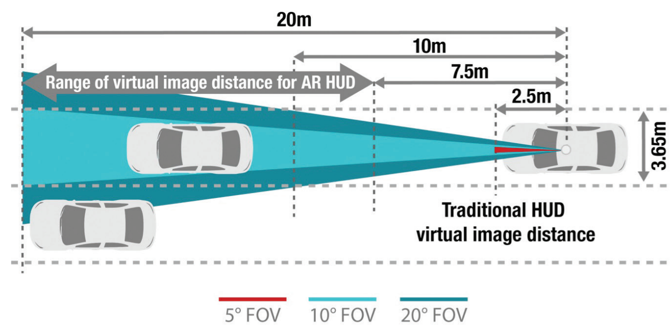


Figure 3. AR HUDs have a VID of up to 20 m, while traditional HUDs have a much shorter VID

Figures 2 and **3** illustrate these FOV and VID differences between traditional (past and present) HUDs and AR (future) HUDs. Notice how in the AR HUD display, the HUD graphics interact with the real world and directly identify the obstacle, whereas in the other displays, the displayed images look stationary, floating out ahead of the driver.

Graphics alignment and lumen budget

One key challenge in AR HUD design is the processing and displaying of graphics based on the vehicle's sensor data, commonly referred to as sensor fusion. Integrating real-time vehicle sensor data and the HUD HMI software to accurately overlay symbols on a rapidly changing environment presents a significant design challenge. In a non-AR HUD, alignment with the real world is not a concern, as the information displayed is not interacting with or augmenting real world objects.

A good example of the alignment challenge is how different eyebox position affects graphic alignment. Accommodating differing driver heights requires adjusting the eyebox height by using a small motor to tilt one of the HUD mirrors up or down. However, tilting the mirror also tilts the optical axis of the HUD, causing the virtual image to lose graphical alignment with the real world, as shown in **Figure 4**.

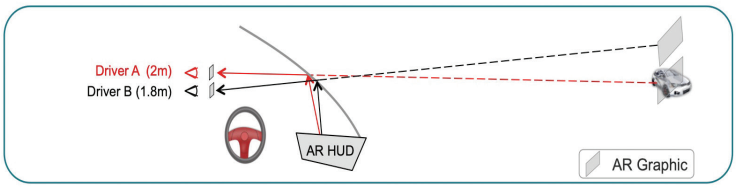


Figure 4. *In an AR HUD, adjusting the eyebox height loses graphic alignment for Driver B*

There are a couple of ways to correct this misalignment: one is to apply more graphics processing combined with a driver monitoring system to compensate for the change in alignment. The other is to design a larger eyebox so the HUD's optical axis does not need to be adjusted and graphical alignment is maintained, as shown in **Figure 5**. Often, a combination of the two approaches is used to support differing driver heights.

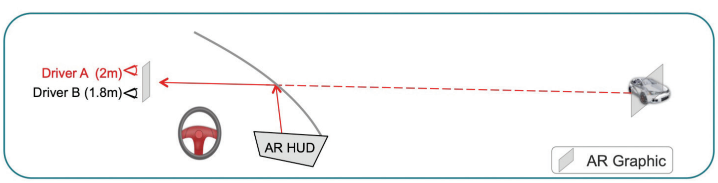


Figure 5. *A larger eyebox supports both Driver A and Driver B*

The larger eyebox is an elegant solution, but comes at the expense of increased lumens. The lumens required to support a HUD design are directly proportional to the FOV and eyebox area. If the eyebox or the FOV area doubles, then the required lumens also double. For example, an AR HUD with double the FOV (4x the area) and double the eyebox height (2x the area) of a non-AR HUD requires 8x more lumens. The lumen budget considerations are shown in **Figure 6**.

The greater the number of lumens, the greater the power consumption and the more challenging the thermal design becomes. This drives the need for an efficient imaging technology. DLP technology is very efficient compared to other competing technologies, with most DLP technology systems achieving efficiencies of >25% (measured in the light in from LEDs to the light out of the DLP projector). The high efficiency of DLP technology significantly reduces thermal design challenges and provides enough lumens to support larger AR FOVs and eyeboxes.

Solar load

Another design challenge found in AR HUDs is managing solar load, or solar irradiance. AR HUDs have larger FOVs and associated "openings" that let in more solar irradiance than traditional HUDs. This, coupled with the longer VIDs and associated higher magnification, creates significant thermal design challenges. Today's non-AR HUDs have optical designs with a magnification around 5x, whereas AR HUDs have magnification on the order of 25x to 30x.

A simple analogy of the negative effects of solar load is what happens when sunlight is focused onto a small spot using a magnifying glass. The solar energy concentrates to a very small unit area, significantly increasing the solar load on that area. Depending on the surface's absorption characteristics, the temperature can rise quite high, resulting in thermal damage.

A DLP technology-based system focuses the solar load onto a transparent diffuser screen, which transmits and diffuses the majority of the sun's energy, resulting in limited heating of the diffuser panel and digital micromirror device (DMD). Thin-film transistor (TFT)-based systems focus the solar load onto a black TFT panel, where almost all of

Lumen budget considerations

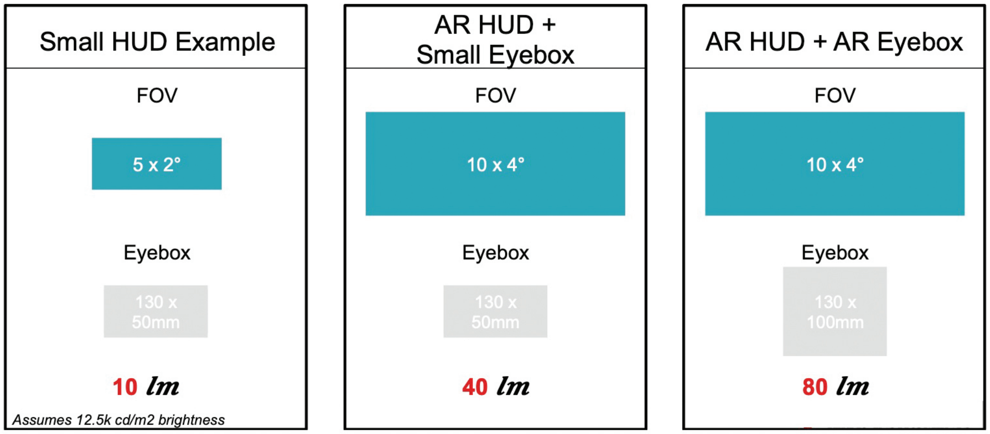


Figure 6. *As the FOV and eyebox increase, more light is required*

the energy is absorbed onto a very small spot, resulting in potential thermal damage. **Figures 7** and **8** illustrate solar load in HUDs using TFT panels compared with those using DLP technology. **Figure 9** shows a DLP Auto picture generation unit (PGU) with diffuser screen.

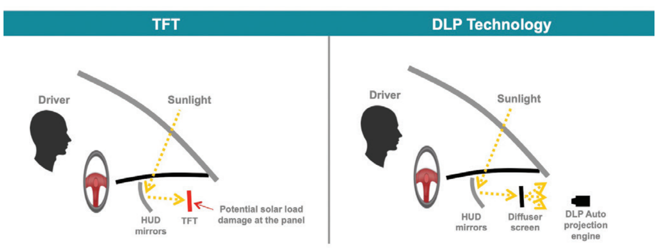
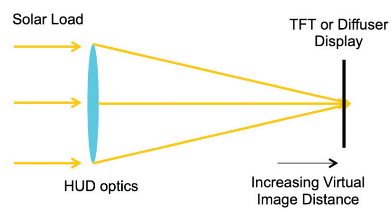


Figure 7. *Comparison of a TFT-based HUD vs. a DLP technology-based HUD*



Spec	TFT	Diffuser
Max Operating Temp	95 to 105°c	150 °c
Sun Light Absorption (Visible Spectrum)	~ 95%	< 1%

Figure 8. *The longer the VID, the more concentrated the solar load*

Constant performance over temperature

Aesthetically, producing a consistent high-quality image over temperature and varying driving conditions is important, but it becomes a requirement when displaying driver-critical ADAS information. An AR HUD needs to produce consistent brightness, color, latency and contrast independent of temperature and driving due to the importance of the ADAS information being displayed. Derating of the image quality is simply not an option.

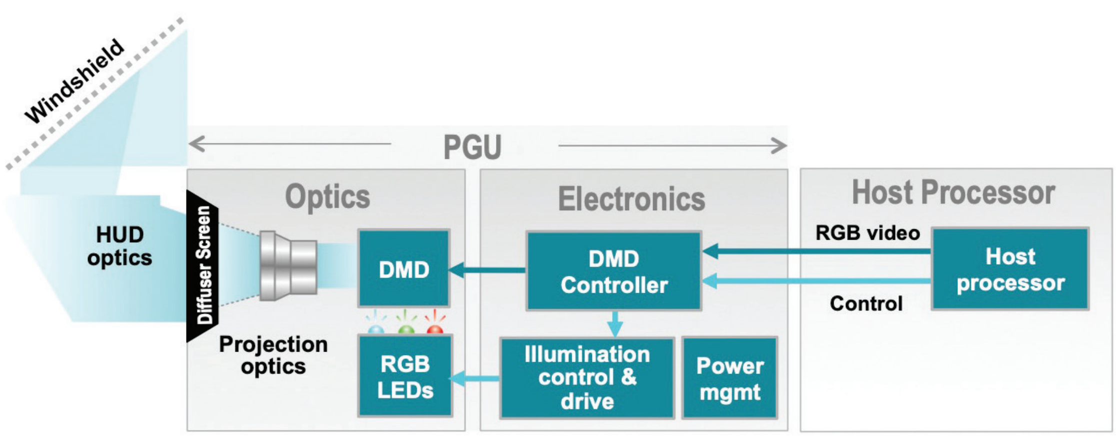


Figure 9. *A DLP Auto PGU with diffuser screen*

The DMD creates the HUD images by rapidly switching thousands to millions of highly reflective aluminum micromirrors on and off. **Figure 10** shows an example array of DMD micromirrors. The physical characteristics and switching performance of the micromirrors do not derate over temperature. For example the micromirrors switch just as fast at -40 °C as they do at 105 °C. The constant performance of the DMD ensures constant image brightness, frame rate, contrast, latency, and color over operating temperature.

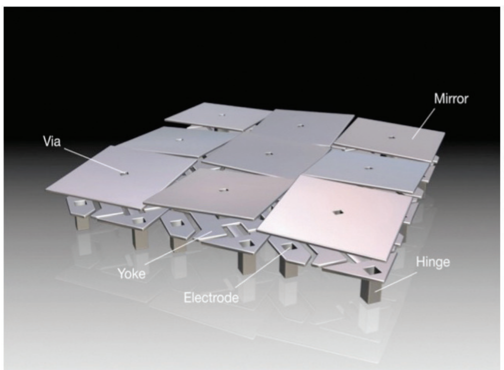


Figure 10. *Example of a DMD micromirror array*

Unfortunately LEDs do derate over temperature losing brightness as the temperature increases. To support constant brightness, the system must be designed to support the maximum target brightness at maximum temperature and then the maximum brightness reduced at the lower temperatures. The challenge in an AR HUD is that the lumen budget is already significantly higher due to the larger FOV and eyebox, and adding support for constant brightness over temperature further increases that budget. It is therefore critical to choose an efficient light source and imaging technology that can support the required lumen budget at minimal power consumption.

Figure 11 shows the lumen output over temperature and associated power consumption of the LED illumination subsystem. As long as worst-case maximum temperature brightness can be supported, the PGU optical power output can be adjusted via software to support a constant brightness over temperature. The dashed blue line represents the lumens needed to support a 10-by-4 degree FOV with a 150-by-130-mm eyebox at a brightness level of 12.5k cd/m^2.

Polarization

Polarized sunglasses reduce glare while driving, but they can block the HUD image in some imaging technologies. **Figure 12** shows the effect polarized glasses can have on a TFT HUD image. This is particularly a problem for an AR HUD, where critical ADAS information is displayed.

DLP technology, however, does not rely on polarized light; HUD images are visible to the driver even when wearing polarized sunglasses. The LED light reflected off the DMD micromirrors consist of approximately 50% P-polarized light and 50% S-polarized light; it's the P-polarized light that's needed when wearing polarized sunglasses.

But it turns out that the windscreen angle has a lot to do with how much P-polarized light reaches the driver's eyebox. The closer the windscreen angle is to Brewster's angle, the less P-polarized light is reflected. Depending on brightness targets a film may need to be added to the windscreen to improve the reflection of the P-polarized light. The advantage of DLP technology is that in many cases, a film is not needed and in the cases that it is required, brightness is higher than competing technologies.

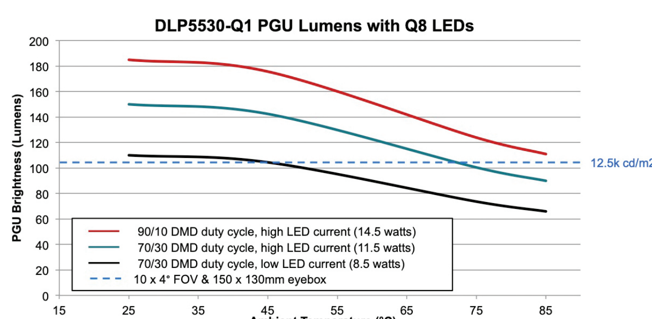


Figure 11. *PGU brightness as a function of temperature, DMD duty cycle and LED current*

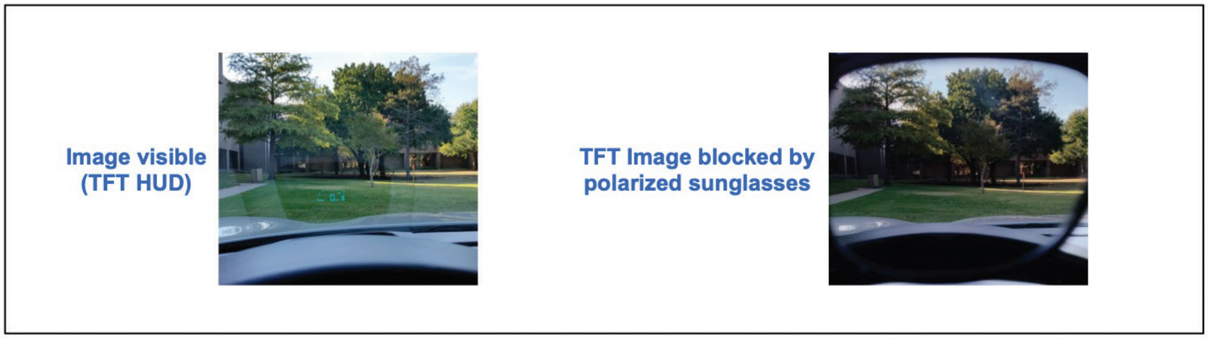


***Figure 12 .** While polarized sunglasses reduce glare, they can also unfortunately filter out TFT-created HUD images*

With DLP technology, you don't need to sacrifice overall brightness in order to see the images when wearing polarized sunglasses, and the image is still visible, as shown in **Figure 13**.

Color saturation

Delivering a bright, vivid, highly saturated image ensures that the HUD graphics are optimally visible under all driving conditions. This is particularly important for the color red, which is used extensively in ADAS as a warning color. It has been shown that reaction times are significantly lowered with increased color saturation. For example,

***Figure 13.** When using DLP technology, polarized sunglasses have no effect on HUD images*

reaction times have been lowered by more than 100ms when increasing saturation levels in red. [1]

Highly saturated colors have also been shown to look sharper and brighter than less saturated colors due to the Helmholtz–Kohlrausch effect [2]. With RGB LEDs, DLP technology supports a 125% National Television System Committee color gamut. **Figure 14** shows DLP technology color gamut for both LED and laser illumination light sources.

Designing with a wide color gamut of highly saturated colors to choose from provides significant HMI design freedom, as well as enabling designs that support quicker reaction times.

Diagnostics and system monitoring

Another important design consideration is diagnostics and system monitoring. AR HUDs have larger displays that are positioned higher up on the windscreen compared to traditional HUDs. If the image were to malfunction, it could potentially block the driver's FOV. Two primary failure modes that need to be detected are a corrupted image and a whiteout/full-on image. If either one of these events were to occur, the system needs to be able to quickly shut the display off. The more diagnostics and system monitoring support that the imager technology provides, the easier it can be to support functional safety goals. For example, the DLP5530-Q1 chipset has extensive diagnostics, built-in self-test, checksums, cyclic redundancy checks and watch dog timers that can help assist customers in meeting their functional safety goals. The overarching idea here is that the HUD image

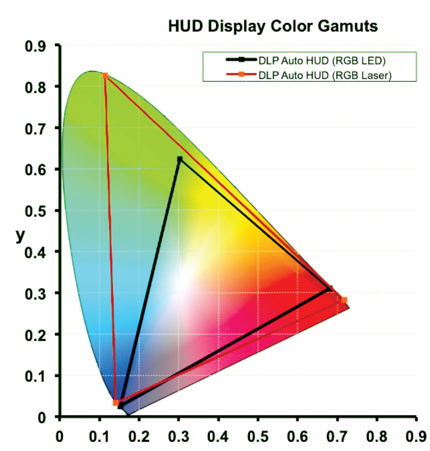


***Figure 14.** HUD laser vs LED color gamuts when using DLP technology*

should never interfere with the driver's view, which would result in the interference of the operation of the vehicle.

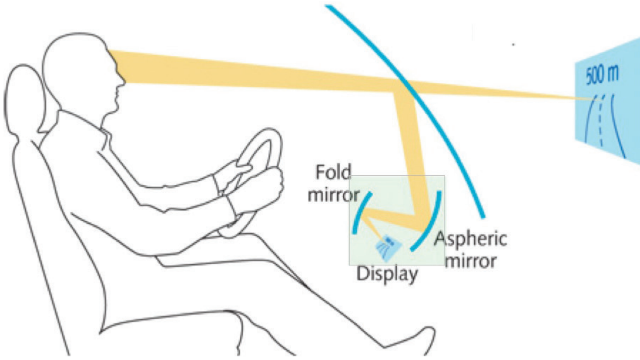


Figure 15. Traditional optics based HUD with large aspheric mirror

HUD size considerations and future trends

Using traditional mirror-based optics, an AR HUD can easily reach 15 to 20 liters. The FOV a HUD supports is directly proportional to the size of its free-form aspherical mirror. If you want a HUD with a large FOV, you have to use a large aspherical mirror which results in a larger HUD. **Figure 15** shows a HUD based on traditional optics.

Trying to carve out 15 to 20 liters in the dash of a car – competing with cross beams; wiring; heating, ventilation and air conditioning; cluster electronics; and the steering column – is no easy task. Even AR HUDs with smaller eyeboxes, around 10 liters, present a significant challenge. To address this challenge, automotive manufacturers are looking at technologies such as waveguides and holographic films.

Both waveguide and holographic film technologies promise to significantly shrink the package volume of an AR HUD, making it easier to fit into the vehicle's dash. Both use holographic elements to replace traditional mirrors. Waveguides can be installed in the vehicle's dash like traditional HUDs, but the height and overall package volume have been significantly

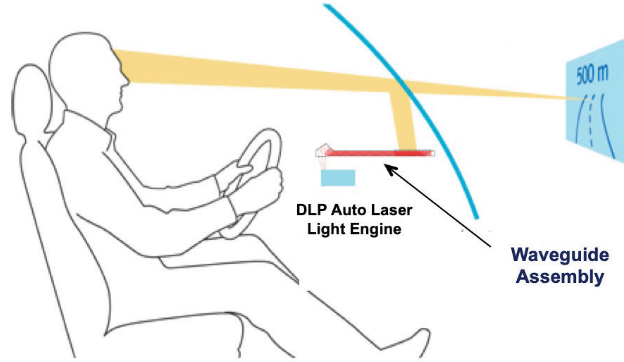


Figure 16. Waveguide based AR HUD

reduced. With a holographic film, a small projector is installed in the dash and a holographic film inserted into the windscreen interlayer. **Figure 16** shows an AR HUD based on a waveguide and **Figure 17** shows an AR HUD based on a holographic film. Both waveguides

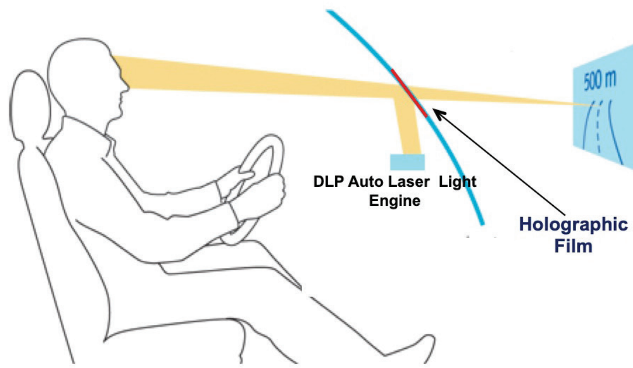


Figure 17. Holographic film based AR HUD

and holographic films have their challenges, but the automotive industry is investing significant capital into these next-generation technologies in order to increase the adoption rate of AR HUDs. These new technologies not only shrink HUD size, but also enable much bigger FOVs, supporting HUDs with 15-by-5-degree FOVs or larger.

DLP technology works with both laser and traditional LEDs, and because waveguides and holographic films will likely use laser-based light sources, DLP technology can support both technologies.

Automotive original equipment manufacturers are beginning to link AR HUDs with autonomous driving and electric cars. With an electric car, you have more space for the HUD, as you no longer have a firewall and combustion engine. Electric vehicles may also require a new body design, so space for the HUD can be reserved early in the design process. Electric cars are also typically equipped with the ADAS infrastructure required to support AR.

When in autonomous driving mode, an AR HUD can provide reassurance to the driver that the vehicle is aware of its surroundings, is in control, and able to take appropriate actions when needed. The AR HUD is also important in supporting the transition from autonomous driving mode to driver control. Depending on the situation, this transition may need to occur quickly – with drivers being forced to stop what they are doing, and immediately take control of the vehicle. The AR HUD can aid in this transition by enabling drivers to quickly assess the driving situation and take appropriate action.

Conclusion

While non-AR HUD systems provide many benefits and have considerably improved driver situational awareness, they still have significant limitations. By increasing the FOV and VID and integrating the vehicle's sensor data to overlay graphics in real time onto real-world objects, AR HUDs will completely change the driving experience and further enhance driver situational awareness and reaction times.

AR HUDs present different and significantly more challenging design problems than today's non-AR HUDs. The use of a high-performance imaging technology such as DLP technology can help solve many current AR HUD design challenges, including:

- Supporting the increased brightness requirements for a large FOV and large eyebox.
- Supporting the increased solar load due to the longer VID.
- Delivering constant image performance over temperature.
- Keeping images viewable when wearing polarized sunglasses.
- Delivering bright, vivid, highly saturated colors.

1 B.M. O'Donell, E. Colombo, and V. Zimmerman, "Chromatic Saturation on Simple Reaction Time"

2 Helmholtz–Kohlrausch effect on Wikipedia

Related resources

- Learn more about automotive HUDs using DLP technology.
- Start your design today with the DLP5530-Q1
- Download the AR HUD lumen budget estimation calculator.