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An Efficient Projector Concept to Meet the Challenge of Signal Road Projection at Daytime

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1. Abstract

The projection of a reversing symbol or a turn indicator symbol onto the road has been demonstrated to increase the visibility of the signal to other road users, thereby potentially mitigating the occurrence of accidents. However, for the projected symbol to be clearly visible and effectively capture the attention of other road users, it must stand out against the background illumination with high contrast. This task is readily achievable during nighttime hours when ambient illumination is minimal. However, it becomes increasingly challenging during daytime hours when the surrounding natural light exceeds 10000 lx. odelo has developed a highly efficient signal projector capable of generating a road projection with luminous intensity values reaching the legal maximum stipulated in proposed regulations. The turn indicator signal projected by the device has a luminous intensity of 2500 lx o 3000 lx, ensuring visibility even during daylight hours, particularly in overcast conditions or shaded areas on sunny days. The device's compact design allows for integration into headlamps or rear combination lamps. The system's high efficiency reduces power consumption to levels that enable passive cooling, a crucial requirement for integrating it into tail lamps.

Keywords: Signal Road Projection, SRP, Near Field Projection, Imaging Optics, Signal Lighting, Turn Indicator, Reversing Lamp

2. Introduction

Cars use signal lights to indicate their intended actions to other road users. This is critical for road safety and helps mitigate accidents. Unfortunately, there are some situations in which a car's signal is not visible to another road user who needs to see and react to it. To address these issues and increase road safety, one proposed solution is to project signals onto the road.

First, this paper examines the influence of mounting positions on the optical efficiency of signal road projectors. Next, we discuss the ambient lighting conditions in which road projections can contribute to road safety. Based on this, we determine the minimum illumination values that a signal road projection system must deliver to create a signal likely to be noticed by other road users. We then present a highly efficient optical solution for a projection system that provides the necessary illumination. Finally, we present our prototype signal road projector, which is small enough to be integrated into automotive signal lamps. Its performance is documented by laboratory measurements and outdoor photographs.

3. Mounting position

An obvious way to add a signal road projector system to a car is to integrate it into the head and tail lamps. The outer lens of the lamp protects the projection system from the environment. Additionally, the lamp has an electric power connection, and the projection system can be controlled via the lamp's communication interface with the car's central control unit.

Designing an efficient optical system is more challenging when high luminous intensity is required because projecting light into a small solid angle brings the system closer to the limit of étendue conservation. Therefore, it is beneficial to position the projector in a way that minimizes the luminous intensity required to achieve the necessary level of illuminance. In general, it is favorable to maximize the ratio of illuminance on the road to the luminous intensity needed to achieve this illuminance. This ratio is inversely proportional to the square of the projection distance.

The position of the car's signal lamps at the corners of the car minimizes the lateral projection distance. The shorter the projection distance, the lower the luminous intensity needed to achieve the desired illuminance on the road. A lower mounting height also reduces the total projection distance for a given horizontal distance on the road. However, a lower mounting height increases the incident angle on the road surface, decreasing the illuminance according to the cosine law. Therefore, there is an optimal mounting height that maximizes the illuminance-to-luminous-intensity ratio for a given projection distance. Figure 1 shows the optimal mounting height for a projection system as a function of the horizontal distance of the projected signal on the road. The optimal projection angle is approximately 35° to the horizontal, independent of the projection distance. The typical height of a head or tail lamp seems very reasonable for an efficient signal road projection.

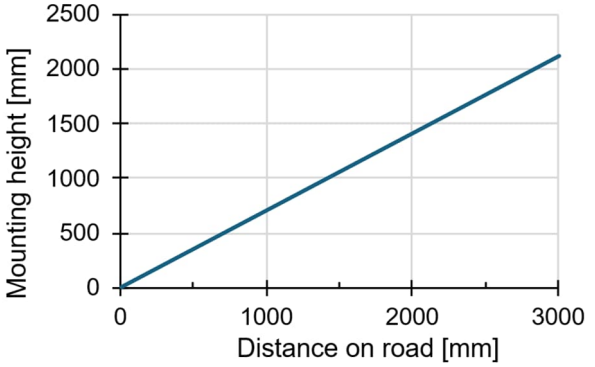

Figure 1: Mounting height above the road level that maximizes the illuminance-to-luminous-intensity ratio as a function of the horizontal distance between the projector's position and the projection on the road.

4. Ambient lighting and required illuminance

Several studies have been conducted on the visibility limit of a projected symbol on the road. A typical parameter to describe the visibility of a projected symbol is the Weber contrast

$$C = \frac{(L_s - L_a)}{L_a} = \frac{L_p}{L_a}$$

where L_a is the ambient illumination, L_s is the total illumination within the projected symbol, and L_p is the illumination the signal road projector would generate without any ambient illumination. The visibility limit of a bright-to-dark contrast depends on several parameters, including ambient illumination, symbol size, presentation time, and observer age. [1]

Certainly, the visibility limit is far from clearly visible. What we consider a clearly visible road projection is subjective and influenced by the surrounding situation. To simplify the matter, it is considered that a Weber contrast C five times higher than the visibility limit is clearly visible.

We use Table 1 to determine the minimum illuminance that a signal road projector needs to generate in order to improve road safety. Reversing lamps are typically designed to support the reversing camera by illuminating the road surface behind the vehicle. Consequently, the illuminance generated by a conventional reversing lamp is often in the range of 3 lx to 5 lx. It seems unlikely that a signal projection would significantly benefit road safety if the light from a conventional reversing or turn indicator is already clearly visible on the ground. The first relevant usage scenario in Table 1 that exceeds this level is twilight. Therefore, a signal road projection should have at least 150 lx.

Table 1: Ambient illumination situations and their typical illumination values and visibility limits, taken from [2]. The last column of the table shows the illumination level L_p that a signal projector needs to generate to produce a Weber contrast C five times greater than the visibility limit.

Ambient condition	Ambient Illumination [lx]	Visibility limit projection [lx]	Clearly visible projection [lx]
Moon light	0,3	0,6	3
Streetlights	9,5	1	5
Driving beam	15	1,2	6
Twilight	750	30	150
Overcast sky	19000	600	3000
Direct sunlight	90000	2000	10000

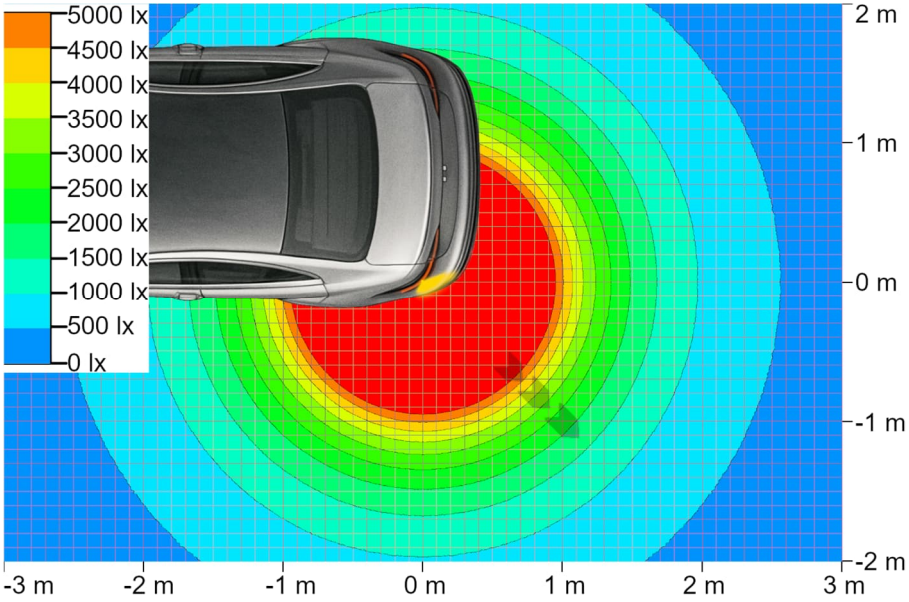

Figure 2: Color scale image of the maximum possible illuminance on the road that can be achieved by a signal road projection system without exceeding the 12000 cd luminous intensity limit set by currently proposed legal regulations. In the image, all illuminance values above 5000 lx are colored red. The position of the turn indicator symbol projected by our prototype is marked in light gray.

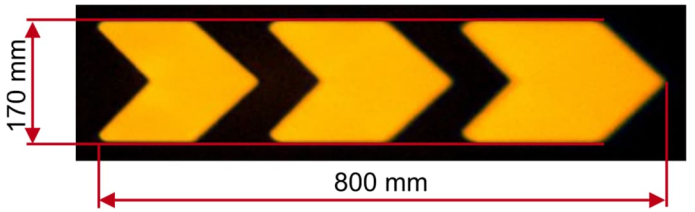

Figure 3: The intended shape and dimensions of the projected signal. It consists of three chevron-shaped segments. Each segment can be activated individually to create a swiping animation.

The legal regulations set the upper limit of the luminous intensity of the light emitted by the projection system at 12 000 cd [3, 4]. Figure 2 shows how it limits the illuminance generated by a signal road projector mounted 800 mm high. A projection that is clearly visible on overcast days (3 000 lx) is only legal at distances up to 1 200 mm away from the projector (measured horizontally, parallel to the road surface). A projection that is visible in full sunlight (10 000 lx) would only be legal at a distance of approximately half a meter from the car. A projection at this short distance from the car is unlikely to improve road safety.

In short, higher illumination increases the visibility of the projection and the ambient conditions under which it is visible. An illumination of more than 3 000 lx is desirable because it extends the use case to the daytime, including overcast days and shaded areas. This extends the operating time from the short periods of dusk and dawn to all day. However, a system that creates more than 3 000 lx conflicts with legal regulations at reasonable projection distances. The goal is obviously a projection system that projects a signal with an illuminance of around 3 000 lx onto the road.

5. Projector setup

We set the mounting height of the signal road projector system to 800 mm above the road level for its development. The projector displays a yellow turn signal on the road. Figure 3 shows the intended shape of the signal projection. The signal consists of three chevron-shaped segments that can be activated sequentially to generate a swiping animation. Its width is 170 mm, and its total length is 800 mm.

The projection begins at 575 mm from the exit aperture of the projector measured horizontally parallel to the road. Consequently, the tip of the last chevron shaped segment is a horizontal distance of 1 375 mm away.

To ensure the signal road projector can be integrated into a car's tail lamp or head lamp, the exit aperture size was set to 20 x 20 mm². The entire optical system,

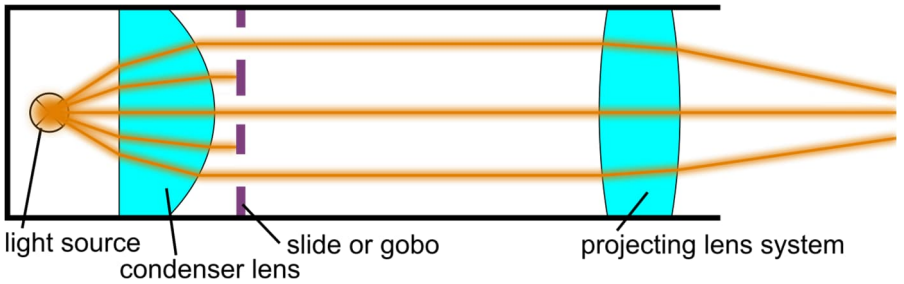

Figure 4: Schematic visualization of the optical setup of a classical projector system. A condenser lens collects the light from the light source. A slide or gobo blocks light in certain areas to form an image. Finally, projecting optics project this image onto a screen.

including the LED light sources and PCB, should be less than 50 mm long. Additionally, active cooling is not an option for tail lamps, so the system must perform efficiently enough to be cooled passively.

As mentioned in Section 4, the goal is to achieve illuminance values of 3000 lx in areas where legal regulations permit. In the remaining areas, the maximum legal luminous intensity of 12000 cd shall be reached.

6. The optical system

As shown in Figure 4, a classical projector setup consists of four elements. First, a light source generates light. Next, collimator optics collect as much light as possible and direct it onto an image-forming element, such as a slide or gobo. A projecting lens system then projects the image onto a screen. A gobo is a stop with one or more apertures that form a black-and-white image, while a slide can create a grayscale or color image. The underlying optical principle is the same for both types. They create an image by blocking unwanted light.

The condenser usually illuminates a circular area. The greater the difference between the intended image and the circular illuminated area, the more light is blocked by the slide or gobo. This often eliminates more than 50% of the light. One of the most important levers for creating an efficient signal road projector is reducing this light loss at the slide or gobo.

The solution we developed does not use slides or gobos. Instead, light guides form the image as shown in Figure 5. The contour of the exit aperture of each light guide shapes a segment of the intended projection. The optical setup uses several LED light sources which increases the available luminous flux. The light guides maximize light collection from the LEDs and direct the light efficiently to the areas

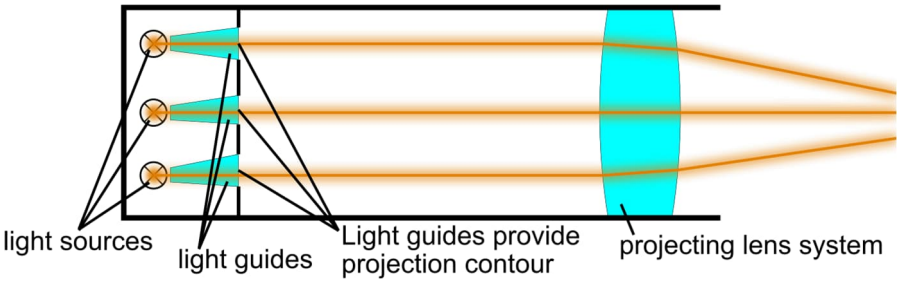

Figure 5: Schematic visualization of the optical setup of the odelo signal road projector. The light from the light sources is fed into light guides that form an image based on their outer geometry. Finally, a projecting lens system projects this image onto the road.

where it is needed for the projection. Having one LED per projection segment also facilitates generating a homogeneous projection on the ground. Adjusting the current through an LED changes the illuminance of the corresponding part of the projection. This allows segments close to the car to be dimmed to reduce inhomogeneity. Of course, this optical setup natively allows for segment-by-segment animation of the projection.

7. Measurement results

Figure 6 shows the prototype of the model signal road projector with a 2 Euro coin for size comparison. A photo of the projected turn indicator signal is shown in Figure 7. To achieve more homogeneous illumination, the segments closer to the car operate at reduced power. The illuminance of the two chevron-shaped segments closest to the car reaches values between 2500 lx to 3000 lx. The chevron-shaped segment at the far end of the projection reaches illuminance levels of 2000 lx to 2500 lx. According to the findings in Section 4 these illuminance values ensure good visibility of the projected symbol on overcast days or in shaded areas. Figure 8 demonstrates this on a sunny winter day.

The goniometer scan of the luminous intensity emitted by our prototype (Figure 9) shows that the luminous intensity of the distant projection segment still exceeds the proposed legal limit. For integration into a car, the luminous flux of the corresponding LED must be reduced.

Our measurements show a total luminous flux within the projection area of over 250 lm. Considering that the system uses three high-power yellow LEDs, the average optical efficiency is more than 30%, with the segment closer to the car being more efficient than the segment farther away.

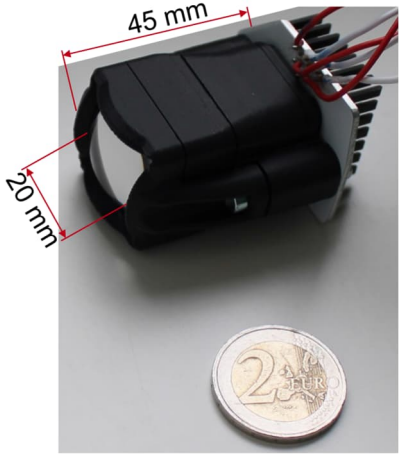

Figure 6: Photo of the odelo signal road projector prototype with a simple 3D-printed housing. The exit aperture measures 2 x 2 cm², and the length without the heat sink is 45 mm.

Figure 7: Photo of the projected light signal on a white surface.

8. Summary

Making a signal road projection visible during the day extends the time period during which it can provide safety benefits from a few hours at dusk and dawn to all day. To achieve this, the illuminance of the road projection should be close to 3 000 lx. Higher illuminance values are not useful due to luminous intensity limits set by legal regulations.

We have developed an optical solution that uses light guides to greatly increase the projector's optical efficiency. Our signal road projector prototype has an aperture of 20 x 20 mm² and a length of 45 mm. It creates a uniformly illuminated turn indicator projection consisting of three chevron-shaped segments with an illuminance of up to 3 000 lx. Measurements verify an average optical efficiency of over 30 %. The projected symbol is clearly visible in the shade during the day.

Figure 8: Photo of the signal road projection in the odelo parking lot in the shade on a sunny winter day. This photo was taken at 4 p.m. on February 3, 2025. No adjustments or manipulations have been applied to the photo, except for obscuring the license plate.

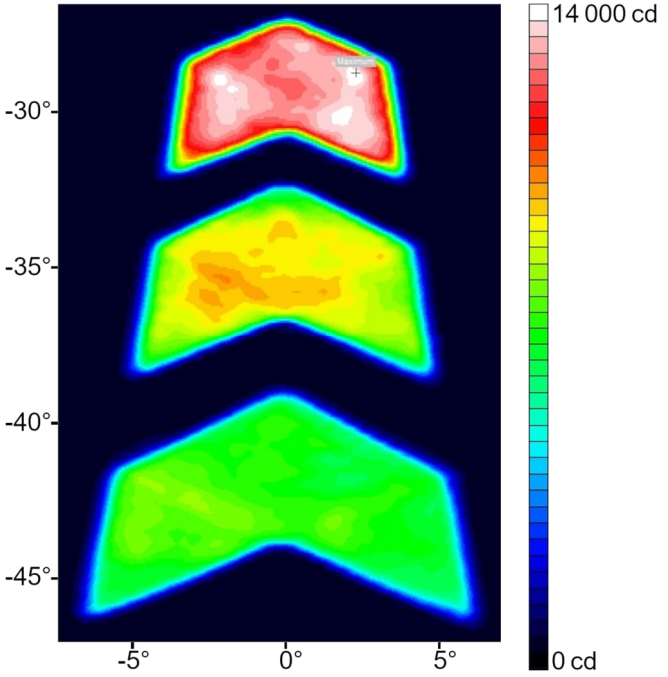

Figure 9: Measured luminous intensity distribution of the odelo signal road projector, displayed on a linear color scale ranging from 0 to 14000 cd.

9. References

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