ISAL 2025
Article DOI: 10.26083/tuprints-00030850
16. International Symposium on Automotive Lighting
Darmstadt, 22. – 24. September 2025
DOI (proceedings): 10.26083/tuprints-00030825

The evolution of surface light guides in automotive signal-lighting

B. Kreipe[1], C. Studeny [1]

1: Volkswagen, Germany

1. Abstract

Surface light guides based on edge-light materials provide a cost-effective solution for achieving homogeneous OLED-like lighting. These elements can be used as freestanding or staggered design components and are widely implemented in both framed (e.g. VW ID.4, ID.Unyx, T-Cross PA, Arteon, Passat, Tayron, etc.) and frameless vehicle designs (e.g. SEAT/Cupra Tavascan, Formentor).

As lamp sizes decrease, packaging constraints become more challenging, creating a need for function integration, such as bifunctional designs. Consequently, high-luminance functions like turn signals and brake lights must also be realised within surface light guide technology.

This paper presents two approaches to achieving high luminance in surface light guides. The first solution integrates micro-optics and a white reflector to enable bi-colour tail and turn signal functionality. We discuss challenges related to colour saturation in clear outer lenses, mitigation strategies, and series implementations. The second solution combines surface and classic light guides to enhance luminance through an edge-boost effect, demonstrated via in-house prototypes and series applications.

Finally, we provide an outlook on future high-resolution applications, including segmented surface elements and hybrid systems incorporating micro-pixel LEDs.

Keywords: Surface light guide, automotive signal lighting, homogeneity, bifunctional design, colour desaturation by ambient lighting, micro optics, edge boost

2. Introduction

Modern taillights increasingly incorporate both functional and decorative illuminated elements, driving demand for advanced surface illumination technologies. For example, the Volkswagen Tiguan MY2021 features a strip-shaped illuminated area on the side of the taillight, serving a primarily aesthetic purpose (Fig. 1). Similarly, the Volvo S60 MY2014 integrates an illuminated surface between two linear light guides. Powered by the adjacent light pipes, this element serves as decorative lighting and represents an early example of surface light guide technology (Fig. 1).

Figure 1: Early examples of surface illumination: Volvo S60 MY2014* with light curtain and VW Tiguan MY2021 with illuminated side area.

The concept of surface light guides has long been employed for interior applications to achieve uniform illumination in instrument clusters and backlit displays (Fig. 2). Traditionally, these systems relied on multilayer diffuser foils. Early implementations for exterior lighting followed a similar approach [2], employing a stack of optical films on the front, a central light guide, a reflective layer at the back, and a surrounding frame (Fig. 3). While capable of delivering homogeneous illumination, such foil based concepts presented several drawbacks. Since no foil back moulding is possible, they require additional processing steps and precise alignment of multiple components, which imposes strict mechanical constraints and higher manufacturing costs. To adapt the principle of homogeneous surface illumination for exterior automotive lighting—and to enable greater styling flexibility—new optical concepts and materials were required.

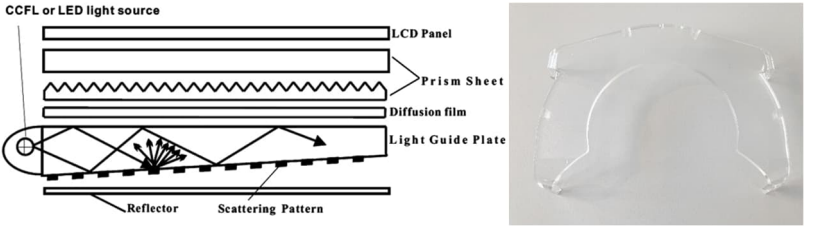

Figure 2: Scheme of a diffusion film based surface light guide (left) [1] and picture of a surface light guide of an instrument cluster backlight (right).

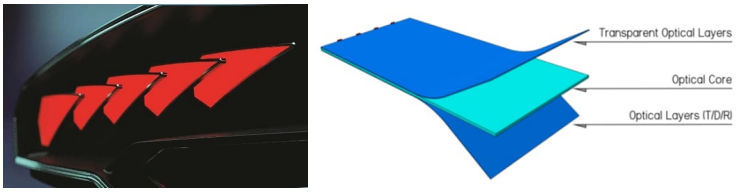

Figure 3: Foil-based surface light guides: mock-up (left) and layer structure (right). Image taken from [2].

Since around 2017, organic light-emitting diode (OLED) technology has set new standards for surface illumination, offering exceptional homogeneity and enabling visually distinctive signature designs [3]. However, the high cost and limited scalability of OLEDs posed a challenge for broad implementation, especially in high-volume vehicle segments. A cost-effective alternative that could achieve a comparable visual effect using more readily available and scalable technologies such as LEDs had to be developed. This effort resulted in the introduction of a novel surface light guide concept in production vehicles such as the Volkswagen Arteon MY2020 and ID.4 MY2021 (Fig. 4).

3. First generation surface light guides

Both the Arteon MY2020 and ID.4 MY2021 (Fig. 4) utilize surface light guides without any visible outcoupling structures. These surface light guides are edge-lit by LEDs, typically from at least one end face. For the first time, a specially developed plastic—referred to as LD12 light-diffusing material—was used as the light-guiding medium [4]. This material incorporates nanometre-sized scattering particles, enabling a highly uniform light distribution across extended distances. The designation "LD12" indicates its ability to maintain homogeneous illumination over a range of 12 cm when light is coupled from both ends [5].

To enhance optical performance, the surface light guides are enclosed by a frame and a white back wall. This design conceals illuminated edges and further increases perceived uniformity through a back-scattering effect (Fig. 5).

Figure 4: Arteon and ID.4 tail lights with surface light guides.

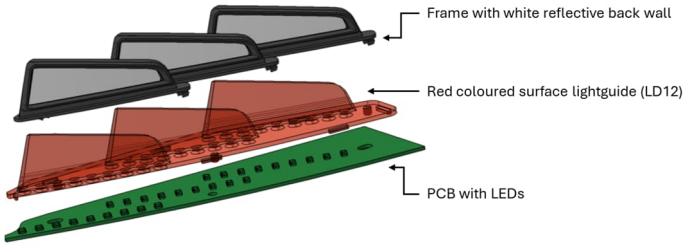

Figure 5: Exploded view of an ID.4 surface light guide element.

Deep red LEDs provide a high quality light colour when lit on. The red appearance in the unlit (off) state is accomplished by incorporating red pigment directly into the light guide material. Since the light emitted from the surface light guide alone does not meet the required photometric values, additional optical elements such as classic light guides are added to the taillamp to ensure compliance with regulatory standards.

A contrasting design approach is demonstrated by the Cupra brand, where surface light guides are implemented without frames or reflective back panels (Fig. 6). In these models, such as the Tavascan and Formentor, intentional overlay effects and glowing edges are used as design features. All in all, surface light guides have been used in a wide range of vehicle projects in both framed and frameless vehicle designs to date.

Figure 6: Cupra Tavascan (left) and Formentor (right) taillights with frameless surface light guide designs.

4. Challenges of modern lamp designs

A prevailing trend in automotive lighting design is the move toward smaller packaging. As available space continues to shrink, the integration of multiple lighting functions within a single element—such as combined tail/stop or tail/turn indicator lights—has become essential. While this approach addresses spatial constraints, it also introduces a number of complex challenges.

High-intensity functions such as stop and turn signals demand either increased optical efficiency or a larger light-emitting surface, both of which must maintain a high degree of homogeneity. Additionally, combining heterochromatic light functions within a single

element is only feasible using transparent light guides. In earlier designs, red outer lenses typically included dedicated transparent sections for non-red functions such as turn indicators. However, with the rise of large-area illuminated elements, the entire outer lens must now be transparent, regardless of the functions it supports.

One of the major challenges with such large, exposed light-emitting surfaces arises from their interaction with ambient light—especially direct sunlight. Because modern transparent lens designs lack the colour-selective filtering properties of red-tinted outer lenses, all reflecting or scattering surfaces within the lamp now interact directly with the full spectrum and intensity of sunlight. This can significantly degrade both the daytime visibility and perceived colour saturation of the lighting function. Some examples for colour desaturation of tail functions are shown in Figure 7.

The use of transparent or white filters and diffusors—including surface light guides with white reflectors—for coloured lighting functions (particularly red) results in colour desaturation. This occurs due to the superimposition of the LED's emission spectrum and the intense ambient light spectrum reflected from the light-emitting surface. This effect is very pronounced in bright daylight and is demonstrated in Figure 8, which shows a simulated shift of the x,y chromaticity coordinates in the CIE colour diagram toward the white point.

Despite these challenges, both optical as well as conceptual countermeasures can be taken to realise robust multifunctional surface light guide elements. Two of these approaches are discussed in the following chapter.

Figure 7: Examples of colour desaturation for sun-exposed light elements: Directly exposed transparent volume elements* (left), white surface elements with micro-optics* (middle) and transparent volume elements* (right) behind transparent outer lens.

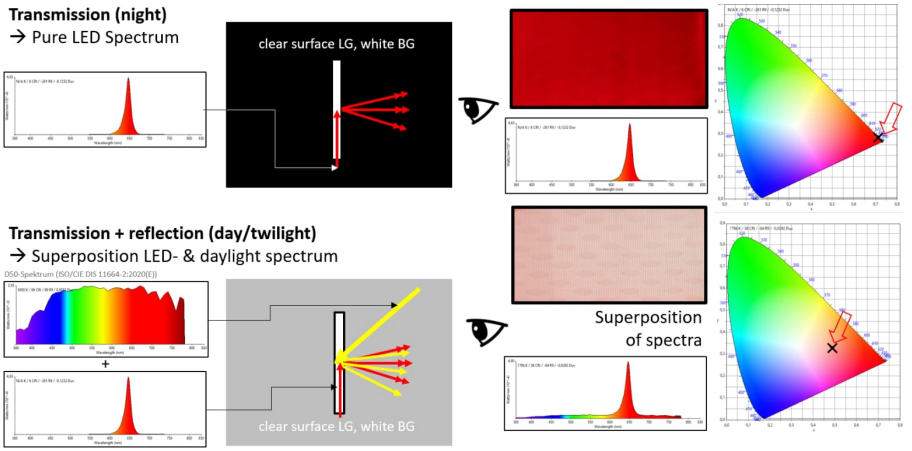

Figure 8: Illustration of colour desaturation by ambient lighting. Comparison of night (upper) and day/twilight (lower) situation.

5. Next generation surface illumination

To extend the applicability of surface light guide technology beyond taillight functions to additional signaling applications, a significant increase in light output is required. Furthermore, the integration of multiple functions within a single optical element allows for efficient usage of limited packaging space, while preserving high optical performance and enabling advanced design solutions. This requires tailored and consistent advancement of surface light guides adapted to the requirements for use in automotive signal lighting. The following section describes two successful technical approaches that have been implemented in production vehicles.

5.1 Micro optics and structuring

The first approach leverages two key parameters to scale luminous flux: the light emitting area and optical efficiency. For this purpose, the surface light guides were enlarged and equipped with micro-optical structures to enhance light extraction. In order to integrate both the red tail light and the amber turn signal into a single illuminated surface, transparent PMMA in combination with a white background reflector is used (Fig. 9). The technical necessity of a completely colourless taillight incidentally marked the beginning of a brief paradigm shift in Volkswagen's design language with the launch of the ID.7.

Figure 9: ID.7 rear lamp signature.

Figure 10 illustrates the structural layout of the ID.7 surface light guide concept. In contrast to first-generation designs, this configuration uses outcoupling optics on the rear side of the surface light guide. These optics are tailored to direct light within the angular range required for both position and turn signal functions, while maintaining a uniform illuminated appearance. The successful concept has since been adopted by several manufacturers [c.f. 6, 7].

The system is further enhanced by a front and rear frame, as well as a structured back reflector. The reflector incorporates light/dark contrast elements that help reduce colour desaturation under ambient lighting conditions (as discussed in Section 4) and contributes to additional visual homogenisation.

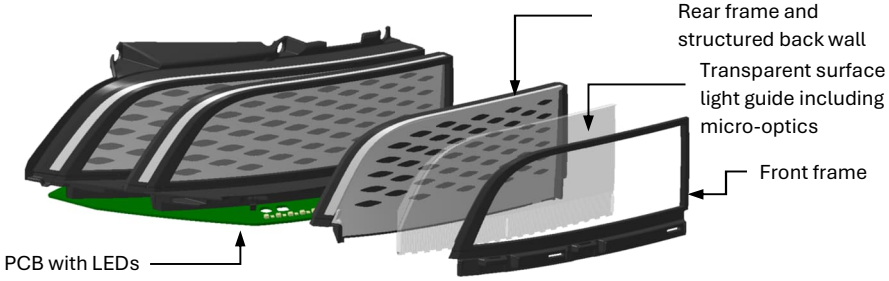

Figure 10: Exploded view of the ID.7 surface light guide.

5.2 Edge-Boost concept

The second approach is an evolution of the established LD12 concept (c.f. sec. 3). A homogeneous LD12 surface light guide is combined with an efficient transparent PMMA lightguide in one element. The LD12 element continues to serve as the tail light function, while the second light guide wraps around it, allowing light to be emitted laterally from its surface (Fig. 11, 12). An optional white separator is placed

Figure 11: Golf 8 MY2024 rear lamp with tail signature and turn indicator.

in between the two light guides to prevent crosstalk and enhance efficiency. The whole stack is housed in a black frame. This dual-guide setup offers multiple advantages. On the one hand, it boosts overall optical efficiency and enables the integration of additional functions, such as a stop light, within the same package. On the other hand, the transparent light guide allows the emission of different light colours from its edge—most notably amber—making it suitable for turn signal functionality. Despite this functional versatility, the distinct red appearance characteristic of rear lighting during the day is preserved through the red tinted LD12 element. Furthermore, the design is inherently immune to colour desaturation under ambient lighting conditions, since scattering surfaces are only made of red material and thus spectrally selective and transparent surfaces show a very low cross-section for backscattering of ambient lighting. Design wise, the elements can be used in the same manner as their monochromatic counterparts as freely positionable elements to create three-dimensional signatures (c.f. Fig. 4, 5 and 11).

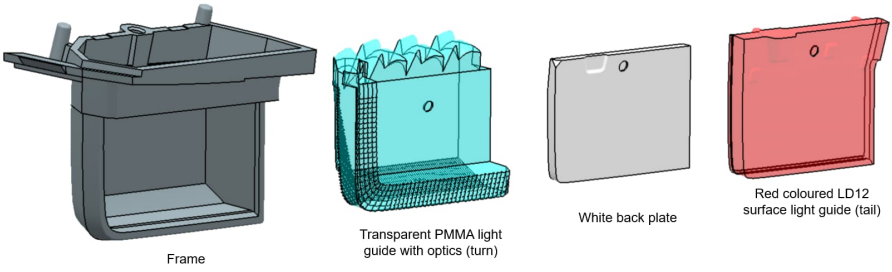

Figure 12: Exploded view of the Golf 8 edge-boost surface light guide.

6. Summary and Outlook

For the first time, bi-functions for automotive signal lighting could be demonstrated in series using surface light guide technology. A combination of taillight and turn indicator was implemented by using different approaches. On the one hand, by scaling the surface area and efficiency using micro-optics. On the other hand, embedding surface light guides into a highly efficient light guide frame. Both optical concepts are robust against colour desaturation caused by ambient lighting, which can occur on exposed surfaces behind transparent outer lenses. This is achieved through various measures to reduce white light scattering. The concepts can be directly transferred to the front of the vehicle to implement position light and turn indicator combinations.

A trend in automotive lighting is the increasing pixelation of light signatures [8,9]. In addition to segmentation of surface light guides, the combination of surface light guides with mini- or micro-LEDs is the next logical step. Meanwhile, several technologies for flat micro-LED panels are available on the market or currently in development, c.f. [10].

8. References

[1] C. Li et al., “Prism-pattern design of an LCD light guide plate using a neural-network optical model”, Optik - International Journal for Light and Electron Optics, 121, 2245-2249, 2010.

[2] T. Gloss et al., “SurfaceLED”, ISAL Proceedings 2017, volume 17, utzverlag GmbH, 2017.

[3] M. Kruppa et al., “DIGITAL OLED for Taillighting – Most Efficient, Homogeneous, and Flexible Display Technology”, ISAL Proceedings 2019, volume 18, utzverlag GmbH, 2019.

[4] PLEXIGLAS Edgelight polymers: https://www.plexiglas-polymers.com/en/plexiglas-edgelight

[5] PLEXIGLAS Edgelight 8N LD12 datasheet

[6] T. Gloss et al., “Micro Surface-LED | Evolution of the S-LED Concept”, ISAL Proceedings 2019, volume 18, utzverlag GmbH, 2019.

[7] M. Vollmer et al., “FlatLight-Technologies enabling new stylings for automotive signal lighting”, ISAL Proceedings 2021, volume 19, utzverlag GmbH, 2021.

[8] C. Studeny, “New Trends and Functionalities in Signal Lighting”, ISAL Proceedings 2019, volume 18, utzverlag GmbH, 2019.

[9] M. Vollmer, D. Duhme, “Beyond Lighting – How Exterior Displays Enhance Visual Communication on the Road”, Proceedings of the 15th International Symposium on Automotive Lighting, WBG Publishing Services, 2023.

[10] E. Lang, U. Hiller et al., “Adaptive signal lighting – Breakthrough technology in LED area lighting and energy saving aspects.”, Proceedings of the 15th International Symposium on Automotive Lighting, WBG Publishing Services, 2023.

[*] Image source: https://www.netcarshow.com/