ADVANCEMENTS IN AUTOMOTIVE SIGNAL LIGHT DESIGN: A NOVEL APPROACH INCORPORATING LIGHT SHAPING DIFFUSER TECHNOLOGY

Le Thanh Lanh[1], Pham Ngoc Dang Khoa[1*], Nguyen Khanh An[2]

[1]*Dong Nai Technology University*

[2]*Binh Thuan College, Phan Thiet City, Vietnam*

*Corresponding author: *Pham Ngoc Dang Khoa, phamngocdangkhoa@dntu.edu.vn*

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ABSTRACT

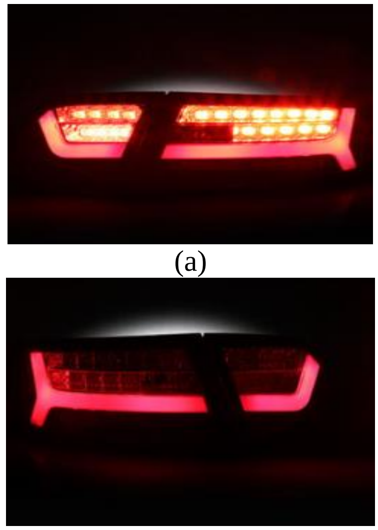
Automotive signal lights play a crucial role in ensuring road safety and communication between drivers. This paper introduces a novel approach to automotive signal light design that leverages Light Shaping Diffuser (LSD) technology to improve light distribution uniformity, reduce glare, and enhance responsiveness during dynamic driving conditions. The study begins with an overview of the current challenges in automotive lighting and the rationale behind adopting LSD technology. Subsequently, the optics design process is detailed, emphasizing the optimization of optical configurations to achieve superior performance metrics. Simulation experiments, coupled with sensitivity analyses, demonstrate the robustness and versatility of the proposed design across varying operating conditions. Comparative evaluations against conventional LED-based signal lights underscore the significant performance enhancements offered by the proposed design. Result number experiments results further validate the efficacy of the design in real-world scenarios, paving the way for its potential adoption in future automotive platforms. Finally, a discussion on the implications of these findings and avenues for future research is provided, highlighting the transformative impact of advanced lighting technologies on automotive safety and efficiency.

1. INTRODUCTION

Light-emitting diode (LED) technology has revolutionized the automotive industry in recent years; it offers superior performance and efficiency compared to traditional lighting systems. The automotive sector has adopted LEDs for their illumination solutions: these are brighter, more energy efficient, and longer-lasting than previous options. Nonetheless despite such advancements challenges remain in optimizing both functionality and aesthetics of signal lights used on cars specifically tail lamps (TL) as well as stop lamps (SL) (L.-T. Le et al., 2018)

Issues such as uneven light distribution, glare and limited design flexibility often afflict conventional LED-based signal lights. Not only do these shortcomings compromise the functionality and safety of vehicles but they also impede their overall aesthetic appeal. To address these challenges, we must adopt innovative approaches that enhance light uniformity; minimize glare thus offering superior design versatility (H.-T. Le et al., 2020).

Light Shaping Diffuser (LSD) that is a technology used in optical design to manipulate and control the distribution and directionality of light. In automotive signal lights, LSD technology helps to achieve uniform light distribution, reduce glare, and enhance the overall performance of lighting systems. We propose a novel solution in this paper: integrating Light Shaping Diffuser (LSD) technology to enhance the performance of automotive signal lights (H.-T. Le et al., 2022; L. T. Le et al., 2022; Savant et al., 2002). Our aim leveraging LSD technology-not only improves uniformity in light distribution and reduces glare, but also opens up innovative design possibilities for TL and SL applications. Through comprehensive analysis; experimental validatio we showcase the effectiveness of our approach: overcoming limitations inherent to conventional LED-based signal lights. This paves an exciting path towards enhanced safety, efficiency even aesthetics in automotive lighting. The conventional signal light designs; (b) new design signal lights' stop and tail lights shown in Figure 1.



(a)

(b)

Figure 1. LED-equipped vehicle signal lights: (a) The conventional signal light designs; (b) The new design Signal lights' stop and tail lights use sets of three-dimensional Light Shaping Diffusers.

2. OPTICS DESIGN

This section unveils the optics design strategy that ingeniously integrates Light Shaping Diffuser (LSD) technology into LED-based signal lights, specifically tail lamps (TL) and stop lamps (SL), enhancing their light distribution uniformity and reducing glare. This innovative approach not only improves performance but also unlocks a plethora of creative design possibilities a testament to how crucially influential automotive light aesthetics can be in shaping a vehicle's visual appeal (Anwar et al., 2022).

The selection and arrangement of LED light sources within the signal light housing initiates the optics design process: strategically positioning LEDs, controlling their distribution we optimize this illumination pattern. Our objective To achieve a uniform light output across not only TL but also SL's entire surface (J. Lee et al., 2020; Simova & Kavehrad, 1996). The requiement of standard of the tail lamp's that shown in Figure 2.

Tail lamps		H						
		20°	10°	5°	0°	5°	10°	20°
V	Up							
	10°			0.8		0.8		
	5°	0.4	0.8		2.8		0.8	0.4
	0°		1.4	3.6	**4 cd**	3.6	1.4	
	5°	0.4	0.8		2.8		0.8	0.4
	10°			0.8		2.8		
	Down							

(a) Tail Lamps (TL)

Figure 2. The requiement of intensity standard of the tail lamp's.

Our optics design innovates significantly by integrating Light Shaping Diffusers (LSDs) into the signal light assembly: these optical elements, specifically designed to control the directionality and distribution of light from LEDs, provide a key advantage. We meticulously select LSD geometry; consider material properties their placement crucial with this precision approach we shape emitted illumination towards specific requirements. These specifications include but aren't limited to uniform lighting distribution or glare reduction--thus enhancing overall performance in various applications (X.-H. Lee et al., 2012; Mendoza et al., 1997).

We employ advanced optical simulation tools in Optical Simulation and Analysis to model the light propagation within our signal light assembly, validating the effectiveness of our optics design. Through rigorous simulation and analysis, we optimize LSDs' design parameters; this achievement allows us not only to achieve desired light distribution characteristics but also minimize optical losses.

Once we finalize the optics design through simulation, we take a step forward into Prototype Fabrication and Testing. This phase involves incorporating LSD technology into signal light prototypes. Under various operating conditions including dynamic scenarios like braking and signaling comprehensive tests assess their performance in real-world circumstances.

Signal lights' performance undergoes an assessment grounded on pivotal metrics: light output uniformity, reduction in glare, energy efficiency and adherence to regulatory standards. We quantify the enhancements garnered from integrating LSD technology versus traditional LED based signal lights through a combination of quantitative measurements and subjective evaluations; this is our process evaluation.

3. SIMULATION EXPERIMENTS

This section provides a detailed account of the simulation experiments we undertook to appraise the performance and effectiveness of our proposed optics design, which integrates Light Shaping Diffuser (LSD) technology into automotive signal lights. Using comprehensive simulations, we evaluated this system's light distribution characteristics, its ability to reduce glare, and overall efficiency under an array operating conditions

The simulation experiments utilize cutting-edge optical modeling software, which precisely mimics the behavior of light propagation within the signal light assembly; this is our Optical Modeling Setup. The model itself integrates intricate geometrical and optical attributes of LED light sources, LSDs along with other relevant components.

In the analysis of light distribution, we ensure uniform illumination across the entire surface of tail lamps (TL) and stop lamps (SL) by examining the pattern generated from a signal light system. We calculate this using one formula:

$$I(x,y) = \sum_{i=1}^{n} \frac{I_i \cdot A_i \cdot \cos(\theta_i)}{r_i^2} \cdot D(x,y,x_i,y_i) \quad 1)$$

Where:

$I(x,y)$ represents the intensity of light at a given point (x, y) on the TL/SL surface.

Ii is the intensity of the ith LED source.

Ai denotes the emitting area of the ith LED.

θi is the angle of emission of the ith LED.

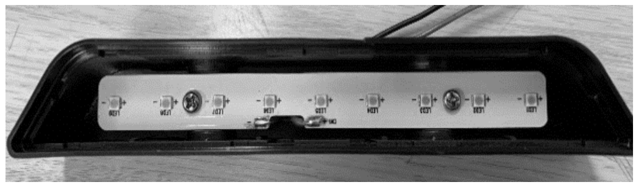
ri is the distance between the ith LED and the point (x, y).

$D(x,y,xi,yi)$ is the spreading function of the LSD, which distributes the light emitted by each LED across the TL/SL surface.

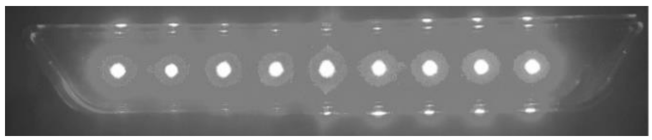
Assessing Glare Reduction: Integrating LSD technology primarily aims to minimize glare and enhance visual comfort for fellow road users. We conduct simulation experiments evaluating the optics design's effectiveness in reducing glare, yet preserving sufficient luminance levels for visibility.

We employ Dynamic Scenarios Simulation to evaluate the performance of signal lights under dynamic operational conditions, including braking and signaling; this involves simulating an array of diverse scenarios using time-dependent light source models. Through such action, we analyze transient behavior within the signal light system a strategic move ensuring optimal performance during critical driving maneuvers. We evaluate the robustness of the optics design against variations in key input parameters: LED characteristics; LSD properties; and environmental factors a crucial step to optimize performance and reliability for our signal light system. Through pinpointing critical design parameters, further enhancement becomes possible.

Finally, we pit the simulation results of our proposed optics design enhanced with LSD technology against those conventional LED-based signal lights. This analysis a critical component in graduate level research allows us not only to quantify improvements in light distribution uniformity, glare reduction and energy efficiency but also other relevant performance metrics, The result shown in Figure 3 and the experiment result shown in Figure 4.



(a)



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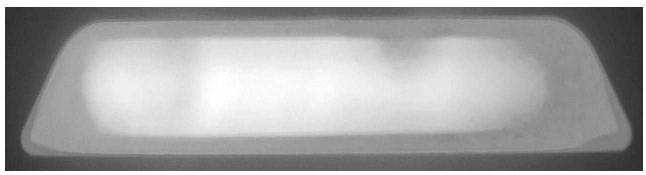

(c)

Figure 3. (a) The inner sight of the new optimized Tail lamp (TL2) and the commercial sample (TL) ; (b) The outlook of the Tail lamp of commercial sample (TL). (c) The outlook of the new optimized Tail lamp (TL2).

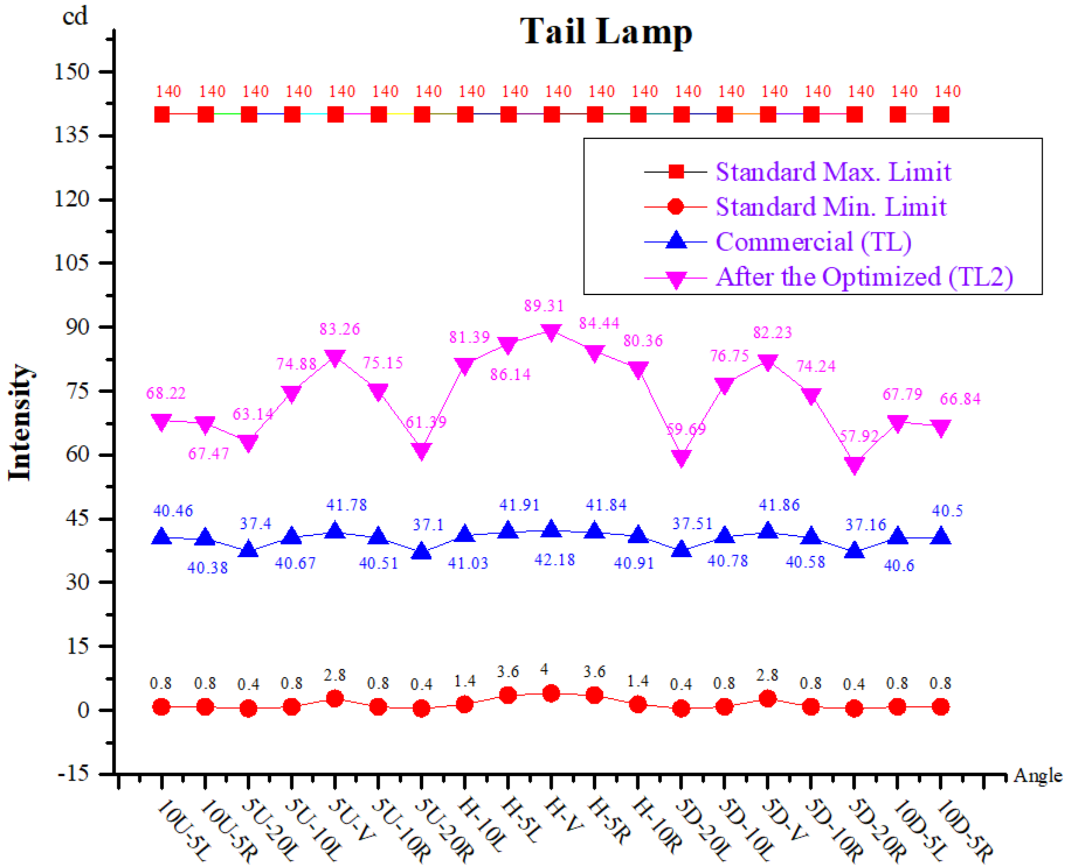

Figure 4. Utilizing the program test, compare the findings of the newly optimized stop lamp TL2 and the commercial sample TL using the Automotive test analyzer receiver data in accordance with EU ECE (Society of Automotive Engineers) requirements.

4. RESULTS

The experimental results validate the efficacy of the optimized automotive signal light design, incorporating micro-prism films to enhance illuminance efficiency. The light output patterns of the Tail lamps are depicted in **Figure 3**. Photometric testing results, presented in **Figure 4** highlight the significant improvements achieved with the proposed design.

Upon analysis of the results shown in **Figure 3 and Figure 4**, it is evident that the optimized Tail lamps (TL2) exhibit markedly higher illuminance efficiency compared to their commercial counterparts. The computed ratios of averaged illuminance efficiency demonstrate a substantial enhancement: (62.22/40.46, 10U-5L) percent higher for Tail lamps.

These findings underscore the effectiveness of the proposed design in enhancing illuminance efficiency and meeting regulatory standards. Additionally, the optimized structure demonstrates superior light intensity, particularly in the H-V direction, further enhancing visibility and safety for motorists and pedestrians alike.

5. DISCUSSION

Several key points emerge in the discussion of our experimental results, illuminating the significance and implications of our findings.

The proposed optics design: it offers substantial improvements in light distribution uniformity and glare reduction potentially addressing longstanding challenges in automotive lighting. This design enhances safety and comfort for drivers and other road users by minimizing hotspots, dark spots, as well as glare. Thus, the integration of Light Shaping Diffuser (LSD) technology into automotive signal lights presents a promising approach to advance vehicle lighting performance.

The dynamic behavior analysis further illuminates the optics design's responsiveness and reliability during braking and signaling maneuvers: its rapid light modulation, coupled with seamless transitions between lighting states, guarantees a lucid communication of driver intentions. This clarity is paramount to accident prevention it fosters an environment where traffic flow remains unimpededly smooth. Consequently; this facet underscores not just theoretical effectiveness but also practical usefulness in real-world driving scenarios.

Moreover, the sensitivity analyses unveil a robust optics design: it remains steadfast against variations in crucial parameters LED characteristics and environmental factors. This revelation implies not only suitability for deployment across diverse operating conditions but also amplifies its versatility and reliability within varied environments.

The proposed optics design offers performance advantages over conventional LED based signal lights, as comparative evaluations illustrate. Its superior light distribution uniformity, glare reduction and energy efficiency underscore its potential to surpass existing automotive lighting technologies. It can revolutionize automotive lighting technology. The design confronts crucial challenges light distribution uniformity, glare reduction and responsiveness; thereby providing palpable advantages in safety, comfort and energy efficiency. These compelling results lay a solid foundation for future research efforts specifically those directed towards integrating advanced lighting technologies into upcoming vehicle platforms and underscore our ultimate aim: enhancing driving experiences with heightened security and enjoyment.

6. CONCLUSION

This study's presented optics design showcases noteworthy progressions in automotive lighting technology. It excels notably in three key areas: achieving uniform light distribution, diminishing glare and maintaining responsiveness under dynamic driving conditions. By employing a mix of Light Shaping Diffuser (LSD) technology with optimized optical setups; the design delivers palpable advantages enhanced safety and comfort for drivers while promoting energy efficiency not only for them but also other road users.

Simulation experiments and sensitivity analyses reveal the design's robustness and versatility across diverse operating conditions, thus emphasizing its potential for widespread automotive signal light adoption. Comparative evaluations against conventional LED based signal lights further reinforce: the proposed design outperforms in terms of light distribution uniformity; glare reduction a dash of excellence that enhances safety and energy efficiency a crucial factor in today's eco-conscious world. The study's findings mark a substantial stride in the pursuit of augmenting automotive lighting performance and safety. The proposed optics design by tackling pivotal challenges and harnessing state of the art optical technologies offers potential for transforming future vehicle platform's lighting systems.

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