TRANSFORMING AUTOMOTIVE DISPLAY BACKLIGHT MODULES: ANALYZING ENERGY EFFICIENCY AND IMPROVING WIDE VIEWING ANGLES

Tran Anh Minh[1*]

[1]*Dong Nai Tecnology University*
*Corresponding author: *Tran Anh Minh, trananhminh@dntu.edu.vn*

GENERAL INFORMATION

Received date: 29/11/2023

Revised date: 16/01/2024

Published date: 12/03/2024

KEYWORD

Vehicle Displays;
Energy Utilization;
Viewing Angles;
Backlight Modules;
Optical Design.

ABSTRACT

This paper revolutionizes the evaluation of in-vehicle display backlight modules through the novel energy ratio of viewing angle concept. A series of experiments validate this innovative approach, showcasing its superiority in assessing energy utilization and reducing errors. The results reveal a 29% improvement in viewing angles (ID) performance and a 12% increase in the energy ratio for Type C lighting patterns compared to Type B. This transformative method offers precision in backlight module design, meeting user expectations for brightness, viewing angles, and energy efficiency. The study emphasizes the role of backlight optical films with wide-angle diffusion functions, aligning with sustainability goals in the transition to electric and hybrid vehicles. This research paves the way for a brighter, energy-efficient future in automotive displays.

1. INTRODUCTION

The automotive industry is currently undergoing a profound transformation, largely propelled by the burgeoning demand for in-vehicle displays utilized across a spectrum of applications including the center console, dashboard, rearview mirror, and rear seat screens. This surge in demand paints a promising outlook for the display sales market, as in-vehicle displays now play an increasingly pivotal role in shaping the modern driving experience. Unlike their traditional counterparts, these in-vehicle screens possess a unique attribute - the ability to command the undivided attention of users during operation. However, the diverse functionalities they serve necessitate precise and distinct viewing angle requirements, a theme underscored by previous research (Chen & Pan, 2018; Fernández et al., 2015; Park et al., 2011).

The center console is tasked with serving as an information hub for both the driver and front-seat passengers. This demands a comprehensive viewing angle and robust brightness to ensure effective information dissemination. Prior studies have delved into potential solutions, often revolving around strategies such as increasing the number of LEDs or opting for LEDs with elevated brightness levels to meet these exacting requirements. However, these approaches come at a considerable cost, underscoring the need to optimize the energy distribution within backlight modules a critical component of their optical design. The ultimate objective is to judiciously concentrate energy within the user's field of vision, thereby averting superfluous energy dissipation. This not only mitigates energy waste but also significantly enhances the overall competitiveness of products within the dynamic display market (Gao et al., 2022; Park et al., 2014).

Building upon the insights garnered from previous research, this study pioneers the concept of the energy utilization rate of viewing angle as a groundbreaking analytical tool for evaluating the energy efficiency of backlight modules. It introduces a guiding framework for the optical design process, enabling the development of tailor-made lighting patterns that seamlessly adapt to a wide spectrum of viewing angles within backlight modules. By aligning energy utilization with specific viewing angles, this innovative method not only enhances efficiency and precision but also heralds a new era of design and performance enhancements for in-vehicle displays. In an epoch where in-vehicle displays continue to redefine the driving experience, the implications of this research hold great promise for the automotive industry (Lv et al., 2014; Zhong & Jha, 2005).

The research embarks on a comprehensive exploration of this concept, elucidating its theoretical foundations and practical applications. Through a series of experiments, the study demonstrates the efficacy of the energy utilization rate of viewing angle as a key metric for assessing energy distribution within backlight modules. It showcases how this innovative approach allows for the development of custom lighting patterns that can adapt seamlessly to the diverse viewing angles encountered in in vehicle displays. The research ultimately seeks to revolutionize the optical design of backlight modules, offering a path toward greater energy efficiency, reduced waste, and enhanced competitiveness in the dynamic field of automotive displays (Park et al., 2011; Qin et al., 2010; Sulyok et al., 2023).

2. METHODOLOGY

The specifications for viewing angles in vehicle displays, which play a pivotal role in the design and performance of in-vehicle screens, are meticulously outlined and standardized by European car manufacturers, as detailed in Table 1. When developing the backlight module for these displays, adherence to these specifications is paramount, with specific attention given to ensuring that the four measurement positions within each designated zone align with the customers' brightness requirements.

For a deeper understanding of these viewing angle specifications, Figure 1 illustrates the range of viewing angles for zones ID18, ID19, and ID20. These zones are purposefully delineated to cater to different viewing scenarios within the vehicle. ID18, characterized by a relatively restricted range of viewing angles, is primarily tailored to meet the needs of users of front-view displays, including the dashboard. In contrast, ID19 encompasses a broader range of viewing angles, catering to onboard entertainment systems intended for rear-seat passengers. The broadest range of horizontal viewing angles is encapsulated within ID20, serving as a dedicated zone for the center console, where both the driver and first officer must have access to crucial information and data. This intricate zoning and angle specification framework underlines the diversity of applications and user requirements in the automotive display landscape, making precise energy distribution within backlight modules a key factor for efficient operation.

The current methodology employed for evaluating the wide viewing angle characteristics of backlight modules predominantly hinges on a performance metric known as ID performance. ID performance is determined by calculating the ratio of luminance at a specified ID viewing angle to the luminance at the center viewing angle. The greater the ID performance ratio, the more effective the backlight module is considered in accommodating a wide range of viewing angles. However, this study introduces a pioneering approach, illustrated in Figure 2, which takes the analysis a step further by concentrating on energy distribution as a primary factor in determining the performance of backlight modules.

The innovative analytical method proposed in this study revolves around the energy ratio of viewing angles. By computing this energy ratio, the evaluation of backlight module performance shifts from a mere luminance-based metric to one deeply rooted in energy efficiency. This transition fundamentally transforms the accuracy of performance assessment, circumventing the inherent limitations of the traditional ID performance metric. A side-by-side comparison in Figure 3 underscores the strong positive correlation between ID performance and the energy ratio of viewing angles. Type C, among the various lighting pattern designs tested, emerges as the exemplar of superior wide viewing angle characteristics.

Comparing Type C to Type B reveals a substantial 29% enhancement in ID performance and a commendable 12% surge in the energy ratio of viewing angles. The pivotal factor driving this significant difference lies in the limitations of ID performance, which solely accounts for luminance disparities between the central and specified ID viewing angles. Consequently, ID performance fails to offer a comprehensive understanding of energy utilization, paving the way for numerical distortions and potential miscalculations in optical design decisions when confronted with partial energy distribution fluctuations within the central luminance. This study thus, underscores the paramount importance of adopting the energy ratio of viewing angles as the fundamental design metric in the development of wide viewing angle backlight modules.

Type C lighting pattern outperforms Type B in a detailed comparison, showcasing a substantial 29% improvement in ID performance and a commendable 12% increase in the energy ratio of viewing angles. This signifies Type C's superior ability to accommodate a diverse range of viewing angles and concentrate energy within the user's field of vision. In details, Type B exhibits lower performance in both metrics, highlighting limitations in energy distribution. The findings underscore the transformative potential of the energy ratio of viewing angles as a fundamental design metric, guiding designers toward backlight module optimization for enhanced competitiveness in the automotive display landscape.

This groundbreaking approach not only enhances the precision of performance evaluation but also bolsters the reliability of optical design decisions, substantially minimizing the risk of erroneous interpretations. By championing the energy ratio of viewing angles, this research contributes to a transformative shift in backlight module design, fostering optimal energy utilization, reduced waste, and the attainment of unparalleled competitiveness in the dynamic realm of automotive displays.

The findings from the aforementioned experiments convincingly demonstrate the effectiveness of the energy ratio of viewing angle in accurately gauging changes in energy utilization within the backlight module. This pivotal insight holds the potential to revolutionize the development and refinement of backlight modules, ultimately leading to the enhancement of product competitiveness.

The research alludes to the ongoing development of backlight optical films equipped with wide-angle diffusion functions, as highlighted in previous research. These films are poised to bring about a paradigm shift in the field by not only elevating the brightness levels associated with wide viewing angles but also by significantly augmenting the overall energy efficiency of backlight modules.

This two-fold benefit, arising from the integration of wide-angle diffusion films, promises to usher in a new era of backlight module design. The anticipated increase in brightness translates to an improved user experience, while the concurrently heightened energy efficiency embodies a commendable leap forward in sustainability and resource optimization. The development of such advanced optical films underscores the dynamic nature of the automotive display industry, where innovation and efficiency go hand in hand to meet the evolving demands of the modern vehicle display landscape.

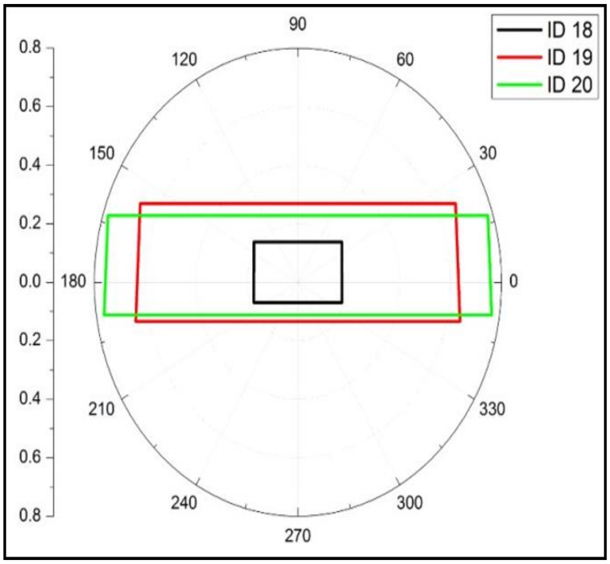
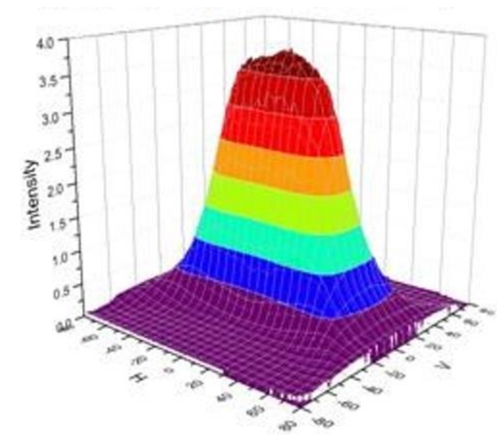


Figure 1. The range of viewing angles for zone ID18/ID19/ID20

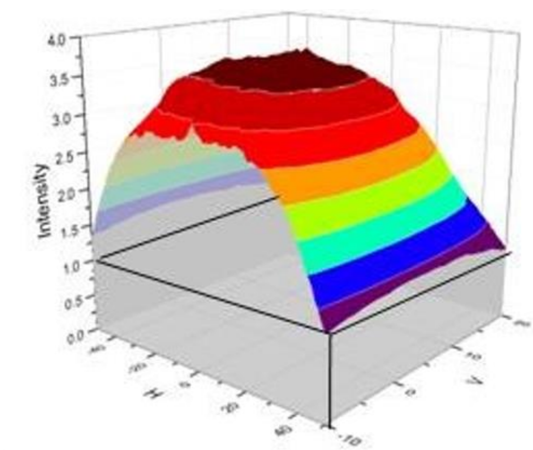
In the realm of in-vehicle displays, the meticulous consideration of viewing angles within designated zones ID18, ID19, and ID20 is fundamental for optimizing user experience and information accessibility. ID18, characterized by a restricted range of viewing angles, is meticulously tailored to front-view displays like the dashboard, ensuring that crucial driving-related information is perceptible to both the driver and front-seat passengers while minimizing distractions. In contrast, ID19, encompassing a broader range of viewing angles, is strategically designed for onboard entertainment systems, catering to rear-seat passengers and accommodating various sitting positions. The broadest horizontal viewing angles are encapsulated within ID20, serving as a dedicated zone for the center console where both the driver and front-seat passengers require access to essential information. This zoning framework acknowledges the diverse applications within the vehicle, allowing for effective information dissemination and user interaction. The thoughtful consideration of viewing angles in each zone is integral to the overall success of in-vehicle displays, ensuring that content visibility is optimized for different scenarios and enhancing the overall user-friendliness of automotive display systems.

Table 1. Viewing angle specification of vehicle display

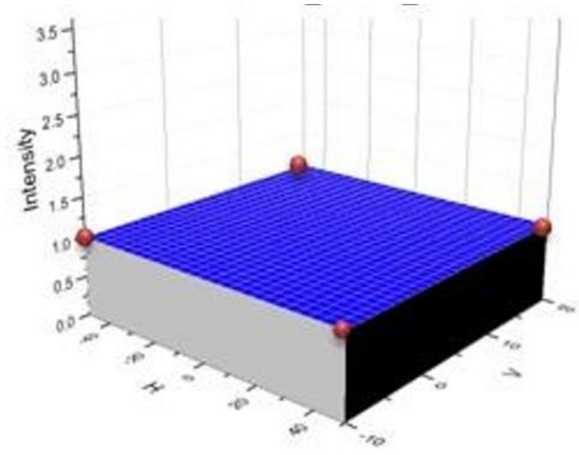
	Cartesian Coordinates		Polar Coordinates	
Zone	**H**	**V**	**theta, θ**	**Phi, ϕ**
ID 18	10	8	12.7	38.6
	-10	8	12.7	141.4
	-10	-4	10.7	201.6
	10	-4	10.7	338.4
ID 19	40	20	42.4	23.4
	-40	20	42.4	156.6
	40	-10	40.6	191.9
	-40	-10	40.6	348.1
ID 20	50	20	51.3	17.0
	-50	20	51.3	163.0
	50	-10	50.3	188.4
	-50	-10	50.3	351.6



(a)



(b)



(c)

Figure 2. Schematic diagram of energy ratio applied to the viewing angle; (a) Horizontal Vertical is $+80^0$&-80^0; (b) Horizontal is$+50^0$ and -50^0 , Vertical is 20^0 to -10^0 ; (c) energy ratio of viewing angle

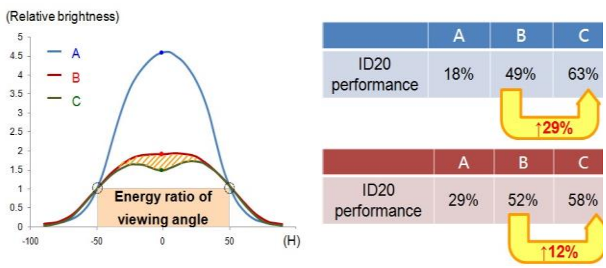


Figure 3. Compares the ID performance and energy ratio of viewing angle of three different lighting pattern

3. RESULT AND DISCUSSION

This illustrative figure provides a visual representation of the specified viewing angles for different zones within the in-vehicle display environment. The zones—ID18, ID19, and ID20—are strategically delineated to cater to specific applications such as the dashboard, rear-seat entertainment, and the center console, respectively. The figure visually communicates the varying degrees of viewing angles allocated to each zone, emphasizing the purposeful zoning strategy to optimize information visibility in different areas of the vehicle, shown in Figure 1

The schematic diagram serves as a conceptual guide to the innovative analytical method introduced in the study, shown in Figure 2 that mean the energy ratio of viewing angles. It visually represents how the evaluation of backlight module performance shifts from a traditional luminance-based metric (as indicated by the ID performance metric) to one deeply rooted in energy efficiency. By focusing on energy distribution across viewing angles, this diagram illustrates a paradigm shift in performance assessment, minimizing the risk of numerical distortions and providing a more comprehensive understanding of backlight module efficiency.

In this comparative shown in Figure 3, the study contrasts the ID performance and the energy ratio of viewing angles for three different lighting patterns, specifically highlighting the exemplary performance of Type C over Type B. The side-by-side comparison underscores the strong positive correlation between ID performance and the energy ratio of viewing angles. Type C exhibits not only a substantial 29% improvement in ID performance but also a commendable 12% increase in the energy ratio compared to Type B. This figure visually validates the transformative potential of the energy-based evaluation approach and emphasizes the critical role of the energy ratio of viewing angles in guiding backlight module design decisions for optimal performance.

a) The energy ratio of viewing angle: a paradigm shifts in evaluation

The innovative concept of the "energy ratio of viewing angle" introduced in this study represents a significant departure from traditional evaluation methods in backlight module design. This new approach capitalizes on energy efficiency as a pivotal criterion, thereby offering a more comprehensive assessment of backlight module performance. The correlation observed between the energy ratio of viewing angle and the traditional ID performance metric reinforces the superiority of the former in accounting for fluctuations in energy distribution. The shift towards this energy-based approach fosters greater precision and reliability in the evaluation of backlight modules. It minimizes the risk of numerical distortions and erroneous design decisions, particularly when confronted with dynamic variations in energy distribution across viewing angles. As such, it lays the foundation for more accurate and effective backlight module designs.

b) Advancing sustainability and competitiveness:

The integration of backlight optical films with wide-angle diffusion functions represents a tangible step towards product improvement and heightened competitiveness in the display market. These optical films are poised to enhance the brightness of wide viewing angles, improving the overall user experience. Simultaneously, they significantly boost the energy efficiency of backlight modules. This dual-pronged advantage is not to be underestimated, as it aligns with the growing demand for sustainable solutions in the automotive industry. The expected reduction in energy consumption aligns with global sustainability goals and the pursuit of more energy-efficient vehicles. In addition to addressing consumer demands for enhanced display quality, this innovation showcases the automotive industry's commitment to resource optimization and environmental responsibility.

c) Future Directions and Implications

The study's findings hold considerable promise for the field of automotive displays. They suggest that the integration of energy-based evaluation metrics can usher in a new era of precision in backlight module design. This could pave the way for the development of displays that not only meet but exceed user expectations for brightness and viewing angles while operating with utmost energy efficiency. Furthermore, as the automotive industry pivots towards electric and hybrid vehicles, the significance of energy-efficient display technologies cannot be overstated. The ongoing research and development of backlight optical films with wide-angle diffusion functions demonstrate the industry's commitment to evolving in tandem with consumer preferences and global sustainability objectives.

This study underscores the dynamic nature of the automotive display landscape, driven by innovations that are poised to reshape the way we interact with in-vehicle screens. By emphasizing the importance of the energy ratio of viewing angle and the development of advanced backlight optical films, this study lays the foundation for a brighter, more energy-efficient future in automotive displays.

4. CONCLUSION

This study introduces a paradigm shift in the evaluation of backlight modules for in-vehicle displays. The groundbreaking concept of the energy ratio of viewing angle significantly enhances the precision and accuracy of performance assessment, departing from traditional luminance-based metrics. The findings, based on a rigorous set of experiments, affirm the validity of the energy ratio of viewing angle as a pivotal tool for optimizing backlight module performance. By reducing the risk of numerical distortions and erroneous design decisions, this approach empowers designers to achieve the delicate balance between brightness, energy efficiency, and product competitiveness.

With the numerical evidence of a 29% improvement in ID performance and a 12% increase in the energy ratio of viewing angles in favor of Type C lighting patterns compared to Type B, the impact of this study is evident. It underscores the transformative potential of the energy-based evaluation approach, heralding a new era of precision in backlight module design. This innovative method aligns with the evolving needs of the automotive display industry and serves as a cornerstone for the development of displays that outperform user expectations in terms of brightness, viewing angles, and energy efficiency.

Moreover, the study underscores the role of backlight optical films with wide-angle diffusion functions, which are under active development. These optical films are poised to elevate the brightness of wide viewing angles while significantly increasing the energy efficiency of backlight modules. The dual benefit they offer signifies the automotive industry's commitment to sustainability and resource optimization, aligning with global sustainability objectives and the transition to electric and hybrid vehicles.

While the study introduces a groundbreaking method with the energy ratio of viewing angle for evaluating backlight modules in automotive displays, several challenges may emerge during its implementation in real-world applications. One significant challenge is the practical integration of this new evaluation paradigm into existing automotive display systems, which may require adjustments to manufacturing processes and technologies. Ensuring cost-effectiveness and scalability while adapting to this novel approach poses another hurdle, as changes in production techniques or specialized components may incur additional expenses. Achieving industry-wide standardization is crucial to avoid inconsistencies in product quality and performance across different manufacturers, necessitating collaborative efforts for widespread acceptance. Additionally, the compatibility of the new method with emerging display technologies and its adaptability to real-world environmental conditions, such as temperature variations and sunlight exposure, must be thoroughly assessed to ensure robust performance. Educating end-users, including car manufacturers and designers, about the benefits and implications of the energy ratio of viewing angle may also be necessary for successful adoption. Overcoming these challenges requires careful consideration, collaborative industry efforts, and a phased approach to implementation to ensure the effective integration of this innovative evaluation method into the dynamic landscape of automotive display technology.

This study backed by tangible numerical results, marks the beginning of a transformative journey in automotive display technology. It signifies a brighter, more energy-efficient future for in-vehicle displays, enhancing the driving experience while contributing to a more sustainable, eco-friendly future. The study underscores the potential for innovation and efficiency in the dynamic automotive display landscape, where user satisfaction and environmental responsibility go hand in hand.

REFERENCES

Chen, B. T., & Pan, J. W. (2018). High-efficiency directional backlight design for an automotive display. *Applied Optics*, *57*(16), 4386-4395.

Park, W. Y., Phadke, A., Shah, N., & Letschert, V. (2011). *TV energy consumption trends and energy-efficiency improvement options* (No. LBNL-5024E). Lawrence Berkeley National Lab. (LBNL), Berkeley, CA (United States).

Rodriguez Fernandez, M., Zalama Casanova, E., & Gonzalez Alonso, I. (2015). Review of display technologies focusing on power consumption. *Sustainability*, *7*(8), 10854-10875.

Park, W. Y., Phadke, A., & Shah, N. (2014). Efficiency improvement opportunities for televisions in India: implications for market transformation programs. *Energy Efficiency*, *7*, 811-832.

Gao, Z., Ning, H., Yao, R., Xu, W., Zou, W., Guo, C., ... & Xiao, J. (2022). Mini-LED backlight technology progress for liquid crystal display. *Crystals*, *12*(3), 313.

Zhong, L., & Jha, N. K. (2005, June). Energy efficiency of handheld computer interfaces: limits, characterization and practice. In *Proceedings of the 3rd international conference on Mobile systems, applications, and services* (pp. 247-260).

Lv, X., Loo, K. H., Lai, Y. M., & Chi, K. T. (2013). Energy-saving driver design for full-color large-area LED display panel systems. *IEEE Transactions on Industrial Electronics*, *61*(9), 4665-4673.

Qin, Z., Wang, K., Chen, F., Luo, X., & Liu, S. (2010). Analysis of condition for uniform lighting generated by array of light emitting diodes with large view angle. *Optics express*, *18*(16), 17460-17476.

Wang, Y. J., Lu, J. G., Chao, W. C., & Shieh, H. P. D. (2015). Switchable viewing angle display with a compact directional backlight and striped diffuser. *Optics express*, *23*(16), 21443-21454.

Sulyok, Á., Erdei, G., Markovits, T., Szabados, G., László Varga, F., & Koppa, P. (2023). Wide field of view flat-panel head-up display system. *Optical Engineering*, *62*(2), 025104-025104.

BIẾN ĐỔI MODULE ĐÈN NỀN HIỂN THỊ Ô TÔ: PHÂN TÍCH HIỆU QUẢ NĂNG LƯỢNG VÀ CẢI THIỆN GÓC NHÌN RỘNG

Trần Anh Minh[1*]

[1]*Trường Đại học Công nghệ Đồng Nai*

*Tác giả liên hệ: *Trần Anh Minh, trananhminh@dntu.edu.vn*

THÔNG TIN CHUNG

Ngày nhận bài: 29/11/2023

Ngày nhận bài sửa: 16/01/2024

Ngày duyệt đăng: 12/03/2024

TỪ KHOÁ

Màn hình hiển thị của xe;
Sử dụng năng lượng;
Góc nhìn;
Mô-đun đèn nền;
Thiết kế quang học.

TÓM TẮT

Bài báo nghiên cứu này trình bày một nghiên cứu về việc thiết kế và đánh giá hiệu suất sử dụng của các mô-đun đèn màn hình hiển thị trong xe ô tô thông qua thiết kế mới với tên gọi nâng cao hiệu suất sử dụng năng lượng và tăng hệ số góc quan sát. Kết quả thí nghiệm cho thấy sự cải thiện về hiệu suất sử dụng năng lượng và các sai số được giảm thấp. Kết quả cho thấy sự góc quan sát tăng 29% và tăng 12% trong hiệu suất tiêu thụ năng lượng cho các mẫu ánh sáng của thiết kế loại C so với thiết kế loại B. Phương pháp nghiên cứu của thiết kế mới này mang lại sự chính xác trong thiết kế mô-đun đèn màn hình hiển thị, đáp ứng yêu cầu của người sử dụng về độ sáng, góc nhìn và hiệu suất năng lượng. Ngoài ra, nghiên cứu nhấn mạnh vai trò của các tấm phim quang học của đèn màn hình với chức năng phân tán góc rộng, phù hợp với mục tiêu chuyển đổi trong quá trình chuyển đổi, áp dụng trên xe điện và xe hybrid. Nghiên cứu này mở ra hướng đi mới cho tương lai ngành sản xuất màn hình hiển thị cho ô tô cũng như nâng cao hiệu suất và tiết kiệm năng lượng trong màn hình trong ô tô.