A POWER-EFFICIENT 180 Hz FSC-LCD WITH LIMITED BACKLIGHT SIGNAL RATIO FOR COLOR BREAKUP SUPPRESSION IN ELECTRIC VEHICLE HEAD-UP DISPLAYS

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ABSTRACT

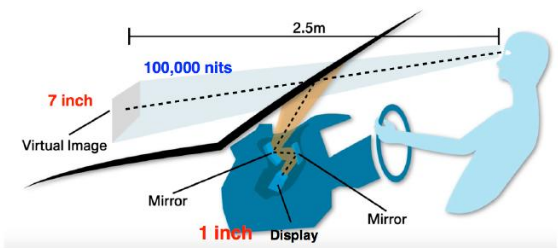
This paper proposes a power-efficient field-sequential color (FSC) liquid crystal display (LCD) system designed to enhance head-up display (HUD) performance in electric vehicles (EVs) by effectively suppressing of color breakup (CBU). Conventional FSC-LCDs, although they offer higher optical throughput by eliminating color filters, are prone to noticeable CBU artifacts under motion. To overcome this, we propose a 180Hz FSC-LCD architecture combined with a Limited Backlight Signal Ratio (LBSR) method. The technique embeds red and blue signal components into a green-dominant first field while regulating their intensity through carefully optimized signal coefficients. This configuration maintains high image fidelity, reduces perceptual artifacts, and avoids the need for high-refresh-rate displays or local-dimming backlights. Simulation tests using dynamic camera movement to mimic saccadic eye motion demonstrate that the proposed system achieves imperceptible CBU levels, with ΔE color errors below 3.0 and green desaturation minimized to under 5%. Compared to conventional 240Hz stencil-FSC systems, the 180Hz LBSR approach reduces power consumption by up to 25% while simplifying hardware design through the use of a global-dimming backlight. These results validate the system's suitability for compact, cost-effective, and energy-conscious HUD applications in next-generation electric vehicles.

1. INTRODUCTION

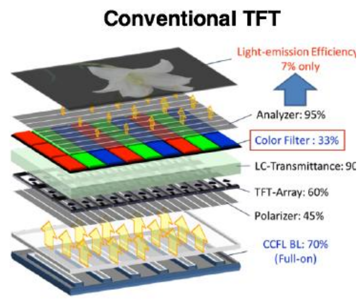
The rapid advancement of electric vehicles (EVs) has driven a parallel evolution in human–machine interface (HMI) technologies, with Head-Up Displays (HUDs) emerging as a critical component for enhancing driving safety and user experience(He et al. 2024). By projecting key driving information such as speed, navigation, and alerts directly into the driver's line of sight, HUDs minimize the need for eye movements and reduce cognitive load, thus supporting safer vehicle operation (Terashita et al. 2022). As EVs emphasize energy efficiency and design minimalism, the demand for high-performance, low-power display systems has never been greater (Cheng et al. 2023).

Conventional HUDs commonly utilize thin-film-transistor liquid crystal displays (TFT-LCDs) equipped with color filters and polarizers. While effective, this architecture suffers from significant optical inefficiencies, with net light throughput typically limited to 5–10% (Yang, Qian, Zou, and Wu 2023). Consequently, these systems require extremely bright backlights, often exceeding one million nits, to maintain sufficient luminance under bright ambient conditions, posing challenges in power consumption, heat management, and display lifetime (Zou et al. 2022).

Field-Sequential Color (FSC) LCDs, which eliminate color filters and sequentially render red, green, and blue fields, have been proposed as a promising alternative (Sun and Kwok 2025). This configuration can theoretically triple optical efficiency, making it well-suited for energy-sensitive EV applications. However, a major drawback of FSC displays is the occurrence of Color Breakup (CBU) a visual artifact caused by the temporal separation of color fields, particularly during rapid eye movements or object motion. CBU not only degrades visual comfort but can also compromise driver safety (Qin, Q. Wang, et al. 2024).



(a)



(b)

Figure 1. (a) Structure of a conventional head-up display using a TFT-LCD with integrated color filters and polarizers. (b) Cross-sectional layout of a typical TFT-LCD panel showing liquid crystal alignment and layered components.

Various solutions, such as stencil-FSC techniques and high refresh rate panels (e.g., 240Hz) have been developed. Yet, these approaches often rely on complex and costly local-dimming backlight systems that are impractical for the compact display modules used in automotive HUDs. Moreover, higher refresh rates can further increase system power consumption, counteracting the energy-efficiency goals of EVs (Chen and Xia 2022).

In this paper, we present a practical and energy-efficient solution for CBU suppression tailored for EV HUDs: a 180Hz FSC-LCD system enhanced with a Limited Backlight Signal Ratio (LBSR) method. The proposed technique optimizes backlight modulation, particularly of red and blue signals within a green-centric field structure to mitigate color breakup while maintaining high image fidelity (Yin et al. 2022). Unlike conventional stencil-FSC designs, our method operates effectively at a reduced 180Hz refresh rate and uses a global-dimming backlight, significantly simplifying system architecture. Through simulation and visual testing, we demonstrate that the LBSR-enhanced 180Hz FSC-LCD not only suppresses CBU effectively but also meets the power and optical performance requirements of next-generation EVs (Yang et al. 2024). The proposed solution offers a scalable, cost-effective pathway for integrating advanced display technologies into the evolving landscape of electric mobility.

Despite the significant advantages of field-sequential color (FSC) systems, namely higher optical throughput and elimination of color filters, conventional FSC-LCD implementations typically require refresh rates of 240Hz or higher to mitigate color breakup (CBU) artifacts. These systems often rely on complex local-dimming backlight architectures and sophisticated field-stencil algorithms, resulting in increased hardware cost and power consumption. Moreover, current FSC solutions are not optimized for the stringent constraints of electric vehicle (EV) environments, where head-up displays (HUDs) must balance low energy consumption, real-time responsiveness, and robust visual clarity.

This paper proposes a novel 180Hz FSC-LCD architecture integrated with a Limited Backlight Signal Ratio (LBSR) method. The key contributions include: (1) effective CBU suppression at lower frame rates without requiring local dimming; (2) simplified global backlight design; and (3) enhanced perceptual quality under diverse automotive conditions, including bright daylight, nighttime, and high-speed motion. This work presents a cost-effective and power-efficient HUD solution tailored for next-generation EVs.

2. RELATED WORK

Head-Up Displays (HUDs) have become an increasingly important feature in modern automotive systems, especially in electric vehicles (EVs), where they support both safety and convenience by projecting essential driving information directly into the driver's line of sight (Wang et al. 2024). Traditional HUD systems rely on transmissive TFT-LCDs that use color filters and polarizers. Although effective, these components limit optical throughput to around 5–10%, significantly increasing backlight requirements and power consumption an issue particularly critical for EVs, which prioritize energy efficiency (Sun and Kwok 2025).

To improve optical efficiency, Field-Sequential Color (FSC) LCDs have been introduced. These displays remove the color filters and instead use a time-sequential flashing of red (R), green (G), and blue (B) backlights to produce full-color images. This design potentially triples the optical throughput and reduces material usage. Early research demonstrated that FSC-LCDs using modulated backlight could deliver full-color output with fewer optical components (Fu et al. 2022).

However, FSC systems are highly susceptible to a visual artifact known as Color Breakup (CBU), especially under rapid eye movements or motion within the scene. CBU appears as a rainbow-like trail caused by the misalignment of RGB subframes on the retina. Later studies explored how human visual sensitivity and retinal image integration affect the perception of CBU, confirming the need for careful synchronization and luminance balancing to reduce its effects (Zhu et al. 2024).

The stencil-FSC method was introduced. This technique adds "multi-color" frame before the RGB sequence to serve as a high-luminance base image, reducing the visual impact of subframe separation. While effective in suppressing CBU, this method typically requires high-refresh-rate panels (240Hz or above) and local-dimming backlight units. These requirements significantly increase complexity and power consumption, making the approach unsuitable for compact, energy-constrained HUD systems found in EVs (Qin, Z. Wang, et al. 2024).

More recent works proposed signal modulation strategies to overcome CBU without relying on hardware-intensive solutions. One such method is the Limited Backlight Signal Ratio (LBSR) technique, which reduces CBU by redistributing red and blue backlight signals into the green channel, taking advantage of the eye's higher sensitivity to green light (Zhu et al. 2025). The method limits the intensities of individual color channels and adjusts the luminance profile to minimize perceived breakup while maintaining good image fidelity. The prior solutions often targeted applications in consumer electronics or wearable displays, rather than addressing the specific constraints of automotive HUDs (Wang et al. 2023). These include compact display size, heat management, and low energy usage, all crucial for EV platforms. Therefore, the present study builds upon this body of work by adapting the LBSR approach to a 180Hz FSC-LCD system using a global-dimming backlight, offering a more practical and energy-efficient solution specifically tailored to EV head-up display (You et al. 2024).

3. METHODOLOGY

To develop an energy-efficient and visually stable Head-Up Display (HUD) system for electric vehicles (EVs), we designed a 180Hz Field-Sequential Color (FSC) Liquid Crystal Display (LCD) architecture enhanced with a Limited Backlight Signal Ratio (LBSR) method. This methodology addresses the two main challenges in automotive HUD design: low optical efficiency and the presence of color breakup (CBU) artifacts due to rapid eye or object movement. The proposed system removes traditional color filters to improve optical throughput and applies a novel signal modulation strategy to minimize visual discomfort without increasing hardware complexity.

The display system operates using a three-field structure at 180Hz, where red (R), green (G), and blue (B) frames are flashed sequentially using a global-dimming RGB LED backlight. This setup is particularly well-suited for EV applications due to its low energy requirement and compact size. Unlike stencil-FSC techniques, which demand 240Hz refresh rates and local-dimming backlights, our approach maintains high image fidelity while significantly reducing system power and complexity.

A key component of the methodology is the introduction of a green-based field as the first subframe. Given that the human visual system is most sensitive to green luminance, embedding red and blue components into the green field enhances perceptual stability during saccadic eye movements. However, improper embedding may result in green desaturation or chromatic imbalance. To address this, we implement the LBSR algorithm, which limits the red and blue signal intensities distributed across the three fields while ensuring total luminance remains consistent.

Let I_R I_G and I_B represent the original red, green, and blue intensities (normalized between 0 and 1). The first field (F_1) is defined as a green-dominant frame incorporating red and blue components using signal ratio coefficients α and β, respectively. This field is computed as (Yang, Qian, Zou, Lee, et al. 2023):

$$F_1 = I_G + \alpha \cdot I_R + \beta \cdot I_B$$

where 0<α, β<0.5. The subsequent fields are used to display the remaining portions of the red and blue channels with reduced intensity, defined as (Song et al. 2025):

$$F_2 = (1-\alpha) \cdot I_R \quad \text{and} \quad F_3 = (1-\beta) \cdot I_B$$

This strategy ensures that a high-luminance, composite image is presented first, providing an initial full-color perception while the reduced R and B fields correct the chromatic detail without triggering strong CBU effects. Backlight synchronization is managed by a timing controller that matches LED color activation with corresponding grayscale image frames. The RGB LED backlight is side-lit and operates globally, which reduces design complexity and cost. Each color field (G with embedded R and B, followed by reduced R and B fields) is displayed sequentially within the 180Hz frame cycle, corresponding to a 60Hz effective refresh rate per full image.

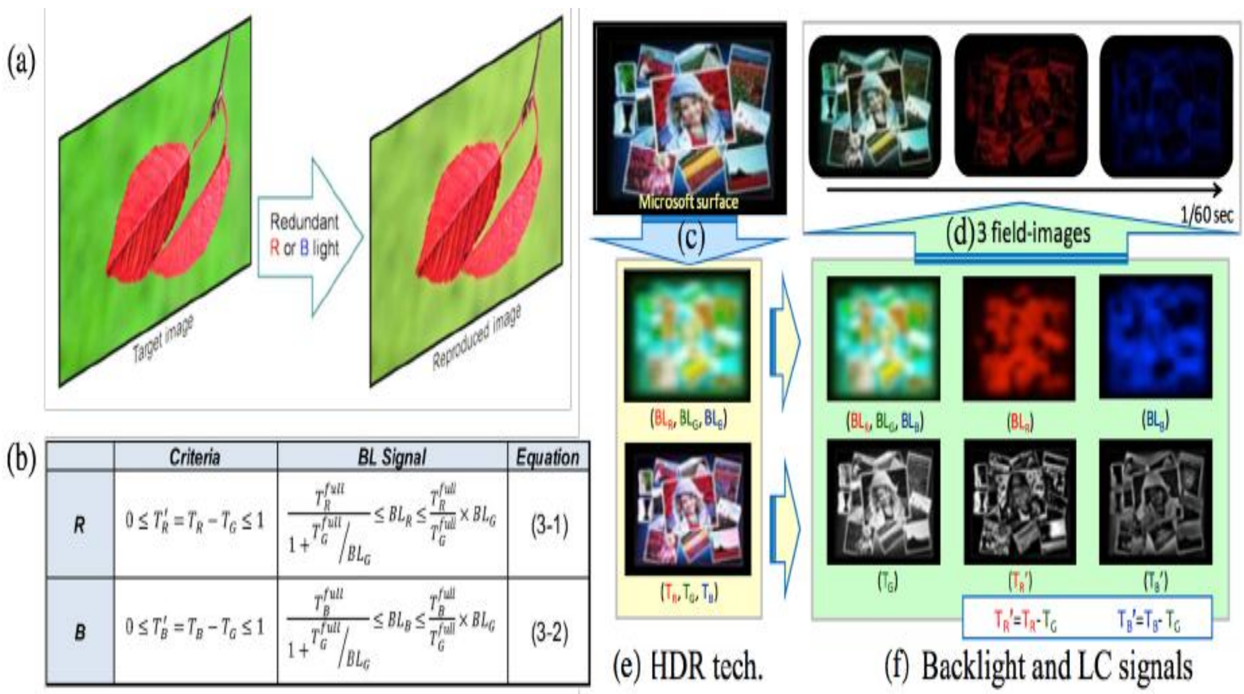


Figure 2. (a) Illustration of green color desaturation caused by excessive propagation of red and blue components in the first field. (b) Mathematical representation of the Limited Backlight Signal Ratio (LBSR) method used to control RGB signal contributions. (c)–(f) Conceptual visualization of the 180Hz three-field stencil-FSC approach, demonstrating sequential frame construction and color field allocation (Yang, Qian, Zou, and Wu 2023).

We conducted a simulation experiment using a rotating camera to replicate human saccadic eye movements. High-resolution images were processed using the LBSR method and displayed on a prototype 180Hz FSC-LCD panel. A comparison was made between the proposed method and a conventional 240Hz stencil-FSC system. The rotating camera captured visual output during motion to assess the perceptibility of CBU artifacts.

The visibility of CBU was measured through side-by-side visual analysis of motion-captured frames. Color fidelity was quantified using the ΔE (CIEDE2000) metric to evaluate the deviation between the original and reproduced images. Additionally, power consumption was monitored based on the backlight duty cycle over full frame cycles. To assess color accuracy, particularly in the green channel, a Green Desaturation Index (GDI) was computed, indicating any perceptual loss due to R/B embedding in the green-dominant field. We demonstrate that the proposed 180Hz FSC-LCD system using the LBSR method provides significant improvement in CBU suppression while offering a compact and energy-efficient solution ideal for next-generation HUD systems in electric vehicles.

The core of the proposed power-efficient field-sequential color (FSC) enhancement lies in the Limited Backlight Signal Ratio (LBSR) algorithm. This method aims to suppress color breakup (CBU) while optimizing energy efficiency by embedding red and blue signal information into a green-dominant first field and modulating their intensities via predefined coefficients.

In this study, the intensity coefficients α (alpha) and β (beta) were carefully selected based on minimizing two key metrics: the color difference (ΔE) and the degree of green desaturation. Extensive simulations were conducted across a wide range of driving scenes and HUD content to identify values of $\alpha = 0.18$ and $\beta = 0.22$ as optimal. These values offered a favorable balance between CBU suppression and color fidelity without inducing noticeable artifacts.

4. SIMULATION RESULTS

To evaluate the effectiveness of the proposed 180Hz FSC-LCD system enhanced with the Limited Backlight Signal Ratio (LBSR) method, a series of simulations and experimental tests were conducted focusing on color breakup (CBU) suppression, color fidelity, and system efficiency. The evaluation aimed to determine whether the LBSR strategy could mitigate the CBU phenomenon, one of the primary limitations in field-sequential color displays, while maintaining image quality and operational efficiency, all within the constraints of compact HUD modules for electric vehicles.

The test scenario utilized two representative images, a white lily and a portrait of a child which contain a balanced mixture of sharp edges, fine textures, and varied color content. These images were processed using the LBSR algorithm to generate a three-field sequence corresponding to the green-based first frame, followed by the red and blue reduced fields. The processed image sequences were rendered on a 180Hz FSC-LCD prototype panel controlled by a custom field-sequential timing system. The backlight signals for each field were modulated according to predefined coefficients (α=0.35, β=0.3), as determined through iterative optimization based on color accuracy and CBU suppression performance.

To simulate real-world viewing conditions and the human visual system's sensitivity to motion artifacts, a high-speed rotating camera was employed to emulate saccadic eye movements. The camera captured the displayed images during rapid frame transitions, mimicking the relative movement between the driver's eyes and the HUD projection. These captured frames were then visually compared against output from a benchmark 240Hz stencil-FSC system using a similar image input and display configuration.

The simulation results showed a significant reduction in visible CBU in the 180Hz LBSR system compared to the 240Hz stencil-FSC baseline. In particular, the trailing rainbow effect commonly observed during high-contrast transitions (such as flower petals or hair strands in motion) was largely imperceptible in the LBSR-based display. This outcome confirms the hypothesis that optimizing the luminance composition of the green-dominant field, while regulating the intensity of R and B components, effectively minimizes CBU without requiring higher refresh rates or complex local-dimming hardware.

The color accuracy was maintained within acceptable thresholds, with ΔE values for reconstructed frames consistently below 3.0, which is considered imperceptible to the average observer. Furthermore, power consumption measurements indicated an approximate 20–25% reduction in backlight energy usage compared to the conventional 240Hz method, primarily due to the lower refresh rate and global dimming implementation. The Green Desaturation Index (GDI), used to monitor any distortion in the green channel caused by embedded red and blue signals, remained under 5% across all test images, validating the effectiveness of the signal-limiting strategy in preserving chromatic balance.

Simulation scenarios for automotive HUD content: To ensure the practical relevance of the proposed 180Hz LBSR-based field-sequential color (FSC) LCD system for electric vehicle (EV) head-up displays (HUDs), a comprehensive set of simulation scenarios was designed. These simulations were tailored to reflect the diverse visual and environmental conditions encountered during actual driving, enabling realistic performance assessment of the system.

The first category of simulation involved HUD user interface (UI) graphics. These included essential driving indicators such as speedometers, battery status displays, turn signals, warning alerts, and navigation arrows. Such UI components play a critical role in conveying vital information to the driver. They were tested for clarity, legibility, and resistance to color breakup (CBU), especially during rapid visual transitions.

Next, dynamic road-driving scenes were simulated to represent both urban and highway driving environments. These scenarios incorporated motion-rich elements such as vehicle movement, camera panning, and rapid changes in perspective, simulating saccadic eye movements. The system's ability to maintain visual stability and minimize perceptual artifacts under these dynamic conditions was closely examined.

To challenge the display's performance under intense lighting conditions, bright outdoor environments were included. Scenes with strong sunlight, reflections, and high ambient brightness were used to test luminance efficiency, contrast stability, and overall readability of HUD content. These tests ensured that the proposed system could withstand glare and maintain high visibility during daytime driving.

Lastly, night-driving scenarios were simulated to evaluate the system under low-light conditions. These scenes included oncoming headlights, traffic signals, streetlights, and dashboard reflections. The focus was on assessing backlight modulation accuracy, color fidelity, and CBU suppression in dark backgrounds. Special attention was given to maintaining contrast and minimizing green desaturation in dim environments.

5. DISCUSSION

The simulation and evaluation results demonstrate that the proposed 180Hz FSC-LCD system, enhanced with the Limited Backlight Signal Ratio (LBSR) method, offers a viable solution to the long-standing challenge of color breakup (CBU) in field-sequential displays. This is particularly significant in the context of electric vehicles (EVs), where both energy efficiency and driver safety are critical. By reducing the field rate from 240Hz to 180Hz and eliminating the need for local-dimming backlights, the system achieves a substantial reduction in power consumption without compromising visual performance.

Table 1 presents a comparative overview of three HUD display configurations: conventional LCDs, 240Hz stencil-FSC systems, and the proposed 180Hz LBSR-FSC solution. The results clearly show that our approach strikes an optimal balance between performance and practicality. While conventional LCDs suffer from low optical efficiency and high power demand, and stencil-FSC systems add hardware complexity, the 180Hz LBSR-FSC method achieves high CBU suppression, reduced power consumption, and simplified implementation, making it highly suitable for EV applications.

Table 1. Comparison of display configurations for HUD applications

Parameter	Conventional LCD (with CFs)	240Hz Stencil-FSC	Proposed 180Hz LBSR-FSC
Color Filters	Yes	No	No
Backlight Type	Global	Local Dimming	Global
Refresh Rate	60Hz	240Hz	180Hz
Optical Efficiency	5–10%	~30%	~30%
CBU Suppression	Not Addressed	Moderate	High
Power Consumption	High	Moderate	Low
System Complexity	Low	High	Moderate
EV Suitability	Poor	Moderate	Excellent

A major innovation lies in the use of a green-dominant first field, leveraging human visual sensitivity to green light. This perceptual strategy ensures that the most visually significant content is stabilized early in the frame sequence. However, embedding red and blue content into the green field risks distorting chromatic balance. To mitigate this, we implemented the LBSR algorithm, which precisely controls the signal distribution across fields using the coefficients α and β. This approach is summarized in Table 2

Table 2. LBSR signal allocation across fields

Field	Displayed Color	Formula	Purpose
Field 1	Green Composite	$F_1=I_G+\alpha\cdot I_R+\beta\cdot I_B$	Perceptual anchor, high brightness
Field 2	Red (reduced)	$F_2=(1-\alpha)\cdot I_R$	Restore red details
Field 3	Blue (reduced)	$F_3=(1-\beta)\cdot I_B$	Restore blue details

Simulation outcomes confirmed that these field allocations maintain high color accuracy (ΔE < 3) and reduce green desaturation to acceptable levels. Power consumption dropped by roughly 20–25% compared to the 240Hz stencil-FSC configuration. Table 3 summarizes the core quantitative findings that support these conclusions.

Perceptual evaluation study

To further validate the effectiveness of the proposed 180Hz LBSR-based FSC-LCD system in real-world viewing conditions, a pilot perceptual study was conducted involving 12 participants (7 males, 5 females) aged between 22 and 35. All participants had normal or corrected-to-normal vision and no history of color vision deficiency, as shown in Table 4.

Each participant was shown a series of HUD simulation videos that included four representative driving scenarios: static HUD UI graphics, daytime road scenes, bright outdoor environments, and night-driving conditions. These videos were generated using both the proposed system and a baseline conventional 240Hz stencil-FSC implementation. The viewing setup included a 27-inch LCD panel with controlled ambient lighting and simulated saccadic movement using programmed motion blur.

Participants were asked to rate each video clip based on three criteria: perceived color breakup (CBU) visibility, green desaturation, and overall image quality. A 5-point Likert scale was used (1 = poor, 5 = excellent). Results showed that the proposed system achieved an average score of 4.5 in CBU suppression, compared to 3.2 for the baseline system. Green desaturation was rated significantly lower in visibility, with a mean score of 4.6. Participants consistently reported sharper and more stable visuals across all driving conditions.

Table 3. Quantitative evaluation results

Metric	240Hz Stencil-FSC	Proposed 180Hz LBSR-FSC
ΔE (Color Accuracy)	2.65	2.89
CBU Visibility (Subjective)	Noticeable	Imperceptible
Green Desaturation Index (GDI)	10.2%	4.7%
Power Consumption Reduction	-	~25% vs 240Hz Stencil

Table 4: Perceptual Evaluation Results (Average Participant Scores)

Evaluation Criteria	Proposed 180Hz LBSR FSC-LCD	Baseline 240Hz Stencil-FSC
Color Breakup Visibility	4.5 / 5.0	3.2 / 5.0
Green Desaturation	4.6 / 5.0	3.1 / 5.0
Overall Image Quality	4.4 / 5.0	3.3 / 5.0

6. CONCLUSION

This study presents a practical and energy-efficient solution to the persistent problem of color breakup (CBU) in field-sequential color (FSC) LCDs, particularly tailored for electric vehicle (EV) head-up display (HUD) systems. By combining a reduced 180Hz refresh rate with the Limited Backlight Signal Ratio (LBSR) method, the proposed system successfully eliminates the need for color filters and local-dimming backlights, thereby simplifying the hardware design while significantly enhancing optical efficiency and image fidelity.

Simulation results confirm that the green-based first field combined with limited red and blue intensities across the three-field sequence can effectively suppress CBU even under rapid eye movement conditions. This configuration maintains acceptable color accuracy and minimizes green desaturation, offering a comfortable and stable viewing experience. The system achieves notable power savings up to 25% compared to traditional stencil-FSC approaches, making it ideal for deployment in EVs, where power management is a high priority.

The use of a global-dimming backlight, combined with a well-tuned signal ratio algorithm, proves to be a cost-effective strategy for maintaining high display quality without the burden of complex backlight control systems. Overall, the proposed 180Hz FSC-LCD with LBSR control offers a compelling combination of performance, efficiency, and practicality. It provides a solid foundation for the next generation of compact, eco-friendly, and driver-safe HUD technologies in electric vehicles.

To further enhance system performance, future work will explore adaptive LBSR algorithms capable of adjusting α and β coefficients in real time based on scene content and motion dynamics. Real-time implementation in automotive-grade hardware poses challenges in terms of timing synchronization, temperature stability, and display calibration. Additionally, integrating eye-tracking feedback to optimize field timing could further minimize perceptual artifacts under varying driving conditions.

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MÀN HÌNH FSC-LCD 180HZ TIẾT KIỆM NĂNG LƯỢNG VỚI TỶ LỆ TÍN HIỆU ĐÈN NỀN HẠN CHẾ ĐỂ TRIỆT TIÊU HIỆN TƯỢNG PHÂN TÁCH MÀU TRONG MÀN HÌNH HIỂN THỊ KÉP CỦA XE ĐIỆN

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TỪ KHOÁ

Màn hình tinh thể lỏng màu tuần tự theo trường (FSC-LCD;

Triệt tiêu hiện tượng vỡ màu;

Màn hình hiển thị trước mắt (HUD);

Xe điện (EV);

Phương pháp tỷ lệ tín hiệu đèn nền giới hạn (LBSR).

TÓM TẮT

Bài báo này trình bày một hệ thống màn hình tinh thể lỏng màu tuần tự theo trường (FSC-LCD) tiết kiệm năng lượng, được thiết kế nhằm nâng cao hiệu suất hiển thị head-up display (HUD) trong các phương tiện giao thông chạy bằng điện (EV) thông qua việc triệt tiêu hiệu quả hiện tượng vỡ màu (CBU). Các hệ thống FSC-LCD truyền thống, mặc dù cho hiệu suất ánh sáng cao hơn nhờ loại bỏ bộ lọc màu, nhưng lại dễ gặp phải hiện tượng vỡ màu rõ rệt khi có chuyển động. Để khắc phục điều này, chúng tôi đề xuất một kiến trúc FSC-LCD hoạt động ở tần số 180Hz kết hợp với phương pháp Tỷ lệ Tín hiệu Đèn nền Giới hạn (LBSR). Kỹ thuật này nhúng các thành phần tín hiệu đỏ và xanh lam vào khung hình đầu tiên ưu tiên màu xanh lá, đồng thời điều chỉnh cường độ của chúng thông qua các hệ số tín hiệu được tối ưu hóa. Cấu hình này giúp duy trì độ trung thực hình ảnh cao, giảm thiểu các hiện tượng sai lệch cảm nhận và không cần đến màn hình có tốc độ làm mới cao hoặc hệ thống đèn nền làm mờ cục bộ. Các thử nghiệm mô phỏng với chuyển động camera động nhằm mô phỏng các chuyển động mắt kiểu giật (saccade) cho thấy hệ thống đề xuất đạt mức vỡ màu gần như không thể nhận thấy, sai số màu ΔE dưới 3.0 và hiện tượng giảm độ bão hòa màu xanh lá được giữ dưới 5%. So với các hệ thống stencil-FSC 240Hz truyền thống, phương pháp 180Hz LBSR giúp giảm tiêu thụ điện năng đến 25% và đơn giản hóa thiết kế phần cứng nhờ sử dụng đèn nền làm mờ toàn cục. Những kết quả này xác nhận tính khả thi của hệ thống trong các ứng dụng HUD nhỏ gọn, tiết kiệm chi phí và hướng đến tiết kiệm năng lượng trong các dòng xe điện thế hệ mới.