Novel Automotive Display Experiences beyond Large Display Areas

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Abstract

This paper presents five automotive user experience innovations that go beyond conventional flat direct-view displays and Head-up Displays. It introduces Scenic View Visor Displays, Under-Display Cameras through OLED technology, true Curved In2Visible Displays, Transparent Sculptural Displays, and, finally, the latest user experience concept unveiled at CES 2025: the Emotional Cockpit. This concept orchestrates multiple emerging display technologies to create an integrated and dynamic in-car experience. Each opportunity is explored through the lens of use cases, relevant display technologies, associated challenges, and practical solutions for implementation.

Author Keywords

Scenic View Visor; Curved In2visible; Transparent Displays; Sculptural Displays; E-ink, MicroLED; FALD; Crystal

1. Introduction

Over many years, the number and size of displays in car cockpits have grown significantly, marking the advent of what is rightly referred to as the 'age of the display in vehicles'. As illustrated in **FIG. 1**, the timeline traces the evolution of automotive displays, from their modest beginnings to the expansive pillar-to-pillar solutions of today, which can reach up to 50 inches in size and transform the cockpit into an immersive environment.

This evolution has profoundly redefined the interior of vehicles, but it also prompts a critical question: **What comes next for user experience in this domain?**

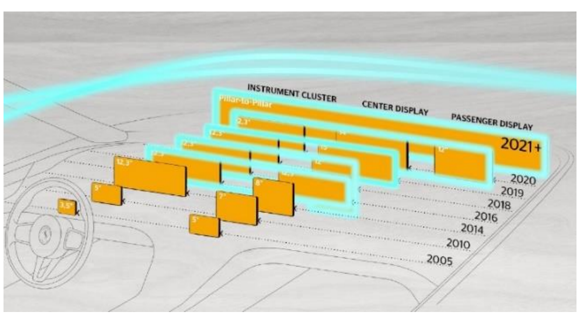
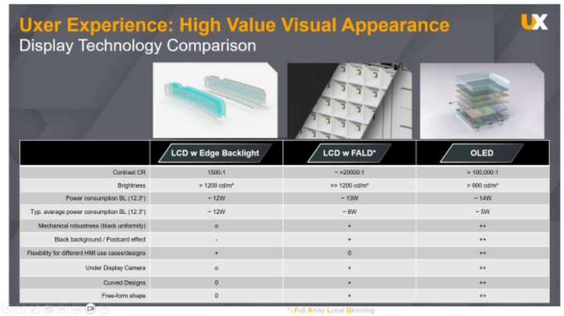


Figure 1. Displays in the car – evolution of display area.

While incremental advancements in display technology — such as the progression from edge-lit LCDs to full-array local dimming (FALD) LCDs, and eventually to OLED displays (as shown in **TAB 1**) — represent an evolutionary path, they may not serve to significantly elevate the user experience. True differentiation demands more than evolutionary improvements. It calls for revolutionary innovations that leverage emerging display technologies, coupled with novel design and functional elements.

Table 1. Technology comparison LCD with edge



	LCD w Edge Backlight	LCD w FALD*	OLED
Contrast CR	1500:1	~ >20000:1	> 100,000:1
Brightness	> 1200 cd/m²	>> 1200 cd/m²	> 900 cd/m²
Power consumption BL (12.3")	~ 12W	~ 13W	~ 14W
Typ. average power consumption BL (12.3")	~ 12W	~ 6W	~ 5W
Mechanical robustness (black uniformity)	o	+	++
Black background / Postcard effect	-	+	++
Flexibility for different HMI use cases/designs	+	0	++
Under Display Camera	o	+	++
Curved Designs	0	+	++
Free-form shape	0	+	++

*) Full Array Local Dimming

This paper introduces a range of next-level user experiences, combining current and emerging technologies into integrated solutions. Each innovation is presented using the following structured approach: use case → problem statement → technology/product solution → technical challenge → status of technology → outlook.

2. Scenic View Visor Display

Moving beyond traditional direct-view displays or pillar-to-pillar systems, we are witnessing the emergence of novel user experiences such as Scenic View Displays and Panoramic Head-Up-Displays (HUD). These technologies create a virtual image above the engine hood, visible as a reflection on the black-printed area of the windscreen, resulting in a panoramic viewing experience (see **FIG. 2** left).

The image source typically utilizes an LCD panel with a FALD backlight for three primary reasons:

1. High luminance levels exceeding 5000 cd/m²
2. Superior contrast that avoids the 'postcard effect'
3. Improved efficiency compared to edge-lit backlights

Unlike traditional Head-Up-Displays, Scenic View Displays allow both the driver and front passenger to view the projected image. The panoramic image spans over the entire, black-printed area of the windscreen and is positioned closer to the driver for enhanced visibility, yet remains comfortably distanced. Additionally, this approach reduces the required luminance by a factor of 10 and minimizes the package space compared to conventional HUDs.

Despite its benefits, the classical Scenic View concept has certain drawbacks, such as limited image brilliance, challenges in windscreen serviceability, reduced cross-carline application potential, and higher system cost. This innovation shifts the reflective surface from the windscreen to a separate visor, such as a glass component (refer to **FIG. 2**, right, and **FIG.3**). This approach enhances system performance and scalability while retaining the immersive user experience offered by the Scenic View concept.

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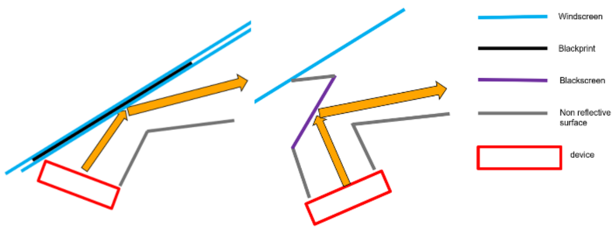

Figure 2. Scenic View display (left side) and Scenic View Visor display (right side) cross section.

The visor overcomes the drawbacks of the Scenic View technology by offering flexibility for use across different carlines. Unlike traditional designs that require multiple windscreen variants, the system can be standardized with a single, unique visor design. Moreover, the effort required for applying reflection coatings to the visor is significantly lower compared to those for the traditional windscreen, resulting in a considerable cost advantage. Additionally, in the event of windscreen replacement during the vehicle's lifetime, the Scenic View Visor Display remains unaffected. This eliminates the need for additional recalibration of the image in service scenarios, saving both time and effort. The overall image quality is also notably more pristine with this approach.

However, one limitation of the Scenic View Visor Display is its design, as it requires an additional component on top of the dashboard, which cannot be entirely avoided.

Figure 3. Scenic View Visor Displays.

Looking ahead, LCDs with FALD (full-array local dimming) systems are already approved and qualified for mass production. And midterm, the next step development of MicroLED displays might enter mass production soon. This advancement is expected to further enhance luminance and efficiency, making the solution even more effective.

3. Under Display IR Camera

One other promising new design opportunity is the UDC (under display camera) based on OLED technology, as illustrated in **FIG 4**. This design addresses technology solutions related to driver monitoring. Until recently, bulky cameras were positioned in the A-pillar or prominently on the top of the dashboard, making the driver feel constantly observed. First attempts were made to incorporate the camera via a notch at the top of the display. However, the optimal integration point is behind the display for two main reasons: (1) the camera becomes invisible, and (2) the center of the instrument cluster displays provides the best location for algorithm performance.

To characterize the system, a balance across five key parameters — infrared transmission (20-30%), resolution (150-200 ppi), lifetime (T80 > 10,000 hours), luminance (> 1,000 cd/m²), and image quality (MTF > 30 lp/mm) — is necessary. For an automotive-grade OLED display, the core challenge lies in designing a proper pixel pattern. The simplest approach is to halve the resolution in a specific camera area to gain the required margin. However, this results in two significant drawbacks: (1) a visible camera area under direct sunlight and (2) a lower-resolution area that must be managed by the application software. Currently, the state-of the-art solutions accepts this compromise by operating at half the display resolution.

Figure 4. UDC (under display camera)

Furthermore, the pixel pattern plays a critical role in achieving the image quality needed for driver-monitoring algorithms. **FIG 5** illustrates a comparison of a reference image without OLED, a distorted image, and an acceptable image as viewed through an OLED display.

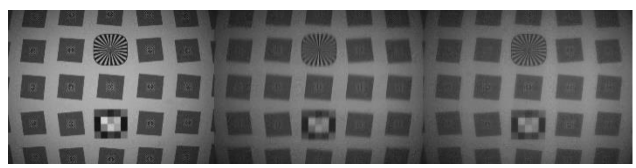

Figure 5. Under Display Camera images. Left: reference image, center: distorted image, right: acceptable image

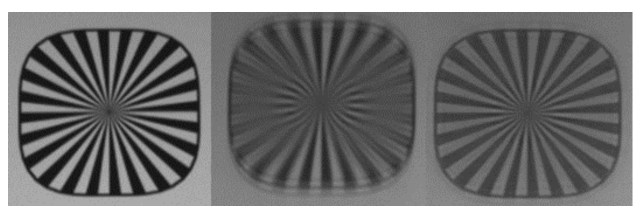

Figure 6. Under display camera images. Left: reference image, center: distorted image, right: acceptable image

FIG. 6 is showing a magnified part of the Siemens star where diffraction effects are clearly obvious, and which may be a not sufficient for driver monitoring algorithms.

As an outlook, the ideal product solution for Under Display Camera requires the next technology step of OLED. These advancements must improve resolution, lifetime, transmission, image quality, and reliability to meet automotive expectations. **FIG 7** presents a spider diagram illustrating the quintuple parameters based on current best-practice results.

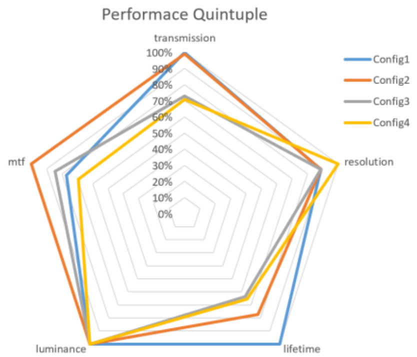

Figure 7. Performance quintuple

While state-of-the-art approaches are acceptable, they fall short of fully meeting user expectations for an Under Display Camera employing the latest OLED technology. In this context, **FIG. 7** config2 emerges as the best-practice solution, offering optimal performance in camera requirements (MTF, transmission) along with reasonable resolution and lifetime performance suitable for automotive applications.

4. Curved In2Visible Display

The next differentiation opportunity involves a decorative surface, such as wood- or carbon-line designs, combining with a flat or slightly curved LCD positioned behind it (refer to **FIG. 8**). This approach enables a shy technology use case, where bulky and prominent black display areas are intentionally avoided, and information if displayed only when and where required. The primary benefit lies in 'de-loading' the driver by reducing unnecessary visual information. Technically, this effect is achieved using a FALD (full-array local dimming) LCD combined with a decorative printed glass or plastic surface.

Figure 8. Classical In2visible Display

At first glance, the reduced displayed content and seamless integration of displays into the dashboard are impressive. However, on closer inspection, designers and experts debate challenges such as:

- Balance between decorative trim functionality and aesthetics (shapes and form language of the car)
- Perception of showing 'fake' wood textures
- Low transmission of ~30% of the decorative surface
- Required luminance of 5000 cd/m² under surface
- Image quality impact of reflective and blurry surfaces

To address these design limitations, the so-called trim surface must support small and different curvatures. This requirement can be fulfilled through injection-molded plastic or hot-formed glass. The preferred display technology for such designs would be plastic-based OLEDs, which offer significant design freedom. However, OLED displays are limited to a luminance of approximately 1000 cd/m², resulting in a shortfall of a factor of three to five. Optimization efforts focusing on increasing OLED luminance and surface transmission would be highly beneficial. Both directions appear achievable in the midterm. For example, switching from traditional absorption pigments to interference pigments could potentially double surface transmission (refer to **FIG. 9**). Additionally, OLED technology promises advancements through innovations like printed OLEDs or photolithographic pixel exposure, which increase the emitting pixel area.

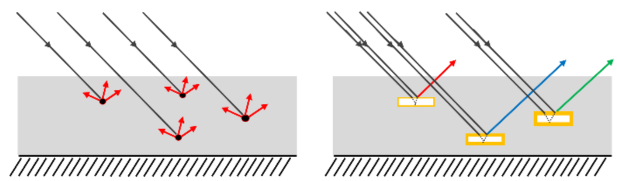

Figure 9. Left side absorption pigments, right side interference pigments.

With that progress, real trim displays are achievable as shown in **FIG. 10**.

Figure 10. Curved In2Visible OLED trim panel

As an outlook, also other demerits of traditional surfaces are highly optimized like image clarity and daylight readability. In addition, film based and stretchable MicroLED technology has the potential to replace OLED on long-term basis with its flexibility properties.

5. Transparent Sculptural Display

Transparent displays are often considered next-generation technology, but identifying the appropriate use case remains a key challenge. For instance, integrating transparent displays into side windows requires freeform shapes and high-brightness transparent display technology to conceal metal wires in the so-called 'non-visible' display area. Similarly, transparent displays with a cover glass face challenges related to mechanical stability when mounted on top of the dashboard. A compelling new use case combines a crystal surface with integrated transparent OLED or MicroLED technology, offering a premium user experience. This concept is illustrated in **FIG. 11**.

Figure 11. Transparent Sculptural Display

This novel transparent user interface, mounted on the dashboard panel, creates a 'magic console' effect when switched off, allowing users to see through to the decorative surfaces behind it. Specially designed facet along the edges enhances light reflection, creating pristine glittering effects. When activated, the display content appears as through embedded in a sculptural appearance, framed by two solid crystals with a depth of 10mm each.

Stack-up description:

1. Front Crystal: 10-mm-thick crystal as outermost layer
2. Laminated Touch Sensor: senses through 10mm
3. Transparent MicroLED Display: Offering a luminance of 3000 cd/m² and approximately 70% transmission.
4. Rear Crystal: 10-mm-thick crystal glued to MicroLED

FIG. 12 illustrates the performance of the touch sensor, demonstrating its ability to operate thorough 10 mm of material thickness with the MicroLED display positioned beneath it.

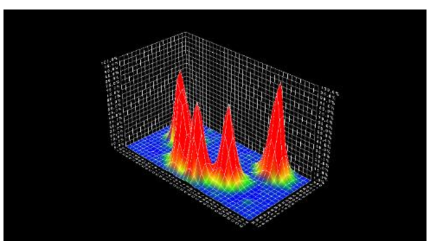

Figure 12. Touch performance chart.

The interactive Sculptural Crystal Display highlights the innovative design possibilities of next-generation MicroLED technology. It represents a significant step forward in luxury display design, aligning with the trend toward premium user experiences.

6. Emotional Cockpit with E-Paper Display

At CES 2025 in Las Vegas, a new 'Emotional Cockpit' is shown, centered around the innovative application of e-paper display technology. This 1.30-meter-wide, energy-efficient display spans across the dashboard and brights e-Paper technology into the automotive sector, offering unique functional and design capabilities. **FIG. 13** shows the user experience which consists of 3 different display technologies combined in one cockpit. The display technology, adapted from e-reader displays, consumes power only during image transitions, making it ideal for energy-conscious applications, particularly in electric vehicles. Unlike backlit displays, the e-paper displays reflect light like paper and can maintain static content indefinitely without power. This feature reduces energy consumption while ensuring clear and reliable visibility to create a unique user experience that can be strongly individualized depending on the user's current preference and settings may be strongly enhanced with AI. Currently available in black and gray, the display creates a minimalist aesthetic while maintaining high durability and lightweight properties. Future advancements in e-paper technology are expected to introduce color capabilities, expanding its functionality and design potential. E-paper displays are very versatile and may also be used to exterior automotive applications. A demonstration vehicle featured an e-paper display integrated into the B-pillar, enabling external vehicle user communication. This technology can display charge levels or other critical information without unlocking the vehicle, enhancing usability and convenience for electric cars. The durability of e-paper displays, their thin profile, and ability to display customizable content without constant power consumption make them a transformative technology for automotive interiors and exteriors alike. By combining functionality with energy efficiency, the integration of e-paper technology marks a significant advancement in additional automotive display solutions.

Figure 13. Emotional Cockpit

7. Conclusion

Interior user experience is one of the most important selling factors for future cars. User experience has become the new horsepower and generate uniqueness and joy of use. All before mentioned display solutions enable product opportunities beyond flat direct view or Head-Up-Displays to ensure an individual customer centric focus. Each single product orchestrates one of the newest automotive display technologies full area local dimming LCD (FALD), OLED, MicroLED and E-Ink.

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