Communication with Exterior Lighting through High Definition Front & Rear Signalling functions

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Abstract: Current trends toward digitalization of exterior lighting and development of L4 - L5 autonomous vehicles emphasises the need and added value of pixelated signalling and lighting systems that are able to communicate. The possibility of displaying symbols and text on the car outer surface answers new usages. It brings signalling to a higher level of interaction and gives a new dimension for stylists to explore.

Display for automotive exterior lighting is a new field of application of display technologies coming from consumer electronics and it brings new technical challenges to ensure that key parameters such as contrast, brightness and reliability are fitting with the exterior lighting environment. Beside contrast and reliability, style and regulation should be taken into account to achieve a regulatory, consistent and harmonious association with existing signalling and lighting functions. Do displays have to be merged with existing signalling functions? How can it be possible and what changes does it imply in terms of styling and performances?

In this paper, we will present how display integration brings different challenges for rear and front lighting systems and how best in class and innovative technologies can be provided to solve these challenges.

Keywords: Display, MiniLED, MicroLED, Automated Vehicles, Communication and pedestrian interaction, Signalling, external Human Machine Interfaces

1. Introduction

Digitalization of exterior signalling is shaping the vehicle design more than ever. Desire of personalization and differentiation will continue growing in the future to enhance brand signature.

This trend is being pushed by the development of the electric vehicle market, which enables higher space for digitalization in exterior vehicle lighting. Digitalization of signalling is also being accelerated by the development of autonomous vehicles: Their uses require communication functions, amongst other safety functions between road users, which can be pedestrian, two wheelers, vehicles and so on.

The implementation of exterior displays is key to answer to Digitalization. Moreover, smart integration and selection of best Display technology will effectively bring signalling to a higher level, improving style, communication features and safety.

In this paper, we will start from the usages of displays in the automotive exterior signalling. Then we will specify exterior Displays: Size and Contrast, according to the usage identified. At last, before focusing on Display technologies, the three next parts will be respectively focused on three key aspects of display integration: Style, Optics and Electronics.

2. Usage of Exterior Display

Exterior Display shall add a new value with new usages to go further in the personalization of the style, the signature of the vehicle and to provide various information to the driver or the other road users. They will also be part of humanising the vehicles with warmer, friendly, engaging and immersive communication.

Figure 1 : Stellantis OpenLab in Germany (Technical University of Darmstadt) display replaced the traditional grill for Internal Combustion Engine

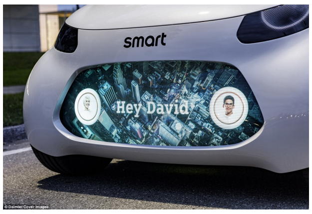

Figure 2 : EV Smart Concept with immersive welcome scenario

2.1 Specific cases dedicated to autonomous vehicles

Exterior displays will also contribute to communication and safety in automated driving

scenarios. They will enable a better acceptance of the autonomous vehicles for the other road users.
The EU Hi-Drive collaborative project, where Valeo is a key partner, addresses a number of challenges to reach high automation readiness, (SAE Level 4 & 5). The project ambition is to considerably extend the operation design domain (ODD) and reduce the frequency of the takeover request by selecting and implementing technological levers. This requires that AV manages its ODD safely but also communicates, interacts, and negotiates with the different road users (Pedestrians, cyclists and other car drivers) to improve flow and reduce conflict. With these aims, Valeo focuses on the (1) definition, and specification of several use cases, (2) study of the road users interactions, (3) establish what types of communication will be used between an AV and pedestrians and (4) investigate how this information can be used to design external HMI (eHMI) for AVs.
Therefore, activities started with an agreement on and definition of relevant Hi-Drive use cases that an AV could be confronted with. The Hi-Drive use cases have been selected using a step-wise process of discussions within the consortium. Starting with literature, accidents statistics analysis and some open brain-storming discussions. The use cases were aggregated and rated against several criteria (such as relevance for safety, need for interaction behaviour etc.) to agree on the most relevant ones. Two relevant use cases were identified where the introduction of a display would add a real value to improve traffic flow and safety, without interfering with other road-user behaviours.

2.2 Use cases

In this part, the two selected use cases are described. The location of the displays will be based on them. These use cases are to be evaluated and showcased in the Hi-Drive demonstrator vehicles at the end of the project. They are the following:

<u>Pedestrian crossing</u>

The Autonomous Vehicle approaches a zone where a pedestrian intends to cross the road. The pedestrian is not sure if he was detected by the AV. The AV communicates that it will wait for pedestrians to cross (C2P) the road.

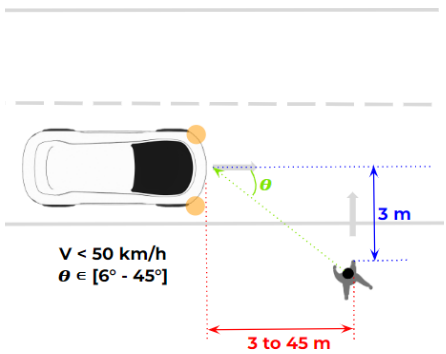

Figure 3 : Pedestrian crossing : Use case description

<u>Departing vehicle from parking lot</u>

The AV gets out from a perpendicular parking while its vision is limited (blind spot). This might cause dangerous situations for cyclists, pedestrians and other vehicles. The AV Indicates the manoeuvring intention of the Valet Parking mode and creates a Safety zone around the vehicle to warn the Vulnerable Road Users about that dangerous situation.

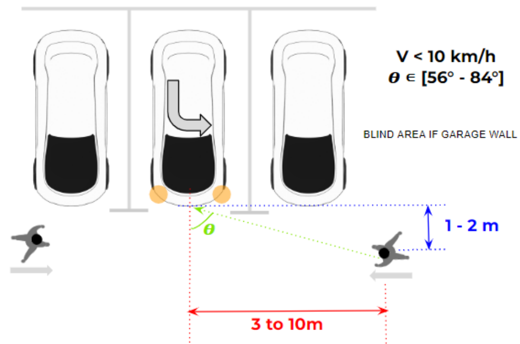

Figure 4 Departing vehicle from parking lot (front) Use case description

3. Display Specifications

Description of above use cases helps to understand the added value of exterior display. Moreover, the distance of observation, dynamic conditions (speed) and environmental conditions are key inputs to build display specifications and provide the required range of display size and required display contrast ensuring good visibility.

3.1 Display Size Specification

The ISAL paper [1] presented by VALEO in April 2022 shows clear specifications of Display size relying on 2 needs : Visibility of display and good identification and understanding of the pattern which is displayed. As shown in Fig 5, Typical display size required for a viewer placed at 20m must be higher than 70mm and must reach 140mm when considering a more complex displayed pattern.

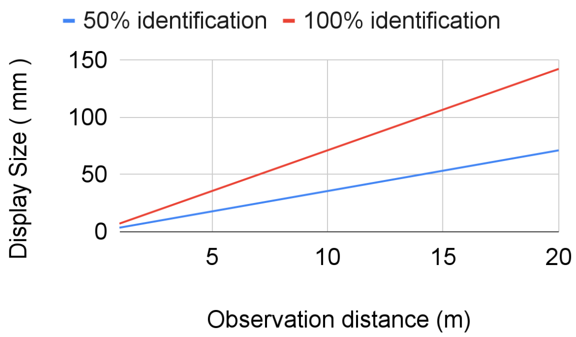

Figure 5: Display size needed for symbol identification

3.2 Display Contrast specification

In addition to size, Visibility of displayed Patterns mainly rely on Contrast between ON display area and OFF display areas. Our Definition of contrast is based on Weber Contrast formula:

$$C_W = \frac{(L_{ON} - L_{OFF})}{L_{OFF}} \qquad [1]$$

where L_{ON} and L_{OFF} are respectively Brightness into ON and OFF areas, as seen also in figure 6 showing display with pedestrian crossing pattern.

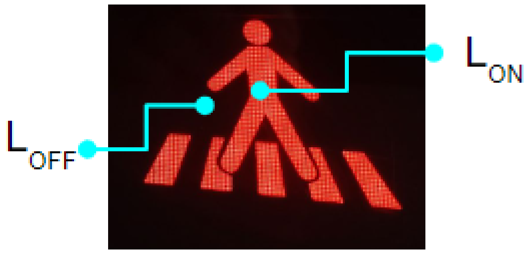

Figure 6: Contrast definition

First approach is to consider Specification of contrast through the theoretical approach of eye sensitivity to contrast. From 1962 [2] to 1993 [3], several measurements have been conducted to evaluate eye sensitivity to contrast before the building of a model by Barten [4] in 1999. Fig 7 shows measurements done in 1978 [5] with a brightness of 100cd/m² and the Barten model is observed in a continuous curve.

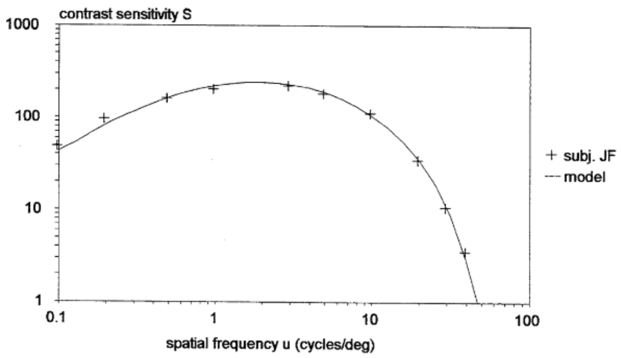

Figure 7: Barten Model & measurement from Howell & Hess (1978)

An important information given by this measurement and this model is the fact that eye sensitivity continuously drops until the value of 50 to 60 cycle/degre. This justifies that higher contrast must be delivered when viewer distance increases as soon as display size remains unchanged. However, Practical use of Barten's model in the context of Automotive signalling remains difficult. Driver's acuity is not always at higher level, pattern is not always placed in central vision and driving situation is obviously not static. This explains that required contrast is by far higher than the contrast given by the model. In addition, comfortable Visibility much higher than physiological threshold has also a positive impact on perceived quality.

If the theoretical model remains a good reference, we have chosen to conduct a field test to evaluate required contrast. More than 20 participants, having various visual acuity and placed at various distances were asked to give their feeling about various pattern visibility and perceived quality. 4 sessions were organised giving the possibility to consider various locations but also various exterior light environments.

The key outcome of all sessions confirmed that Weber contrast must be Higher than 2, and sometime more when considering higher distance.

3.3 Coming back to usages

Considering the 2 usages presented in previous part, we can conclude on the following specifications:

Usage	Display Size Must	Display Size Nice to have	Weber Contrast Must	Weber Contrast Nice to have
Pedestrian crossing	120 mm	220 mm	3	4
Departure vehicle from parking lot	40mm	80mm	2	3

Figure 8 : Display Specification according to usage

4. Integrations and Styling

4.1 New features

In the automotive industry sector, LEDs and OLEDs have opened up new horizons in the field of style and functionalities. Enhanced Design freedom was made possible, through the graphic treatment of light in 2 or 3 dimensions and it's also brought a degree of animation, thanks to the electronic control of each element giving an evolution of the functionalities: running turn indicators, proximity warning, customization of lit areas or leaving home scenarios are significant examples of these functionalities.

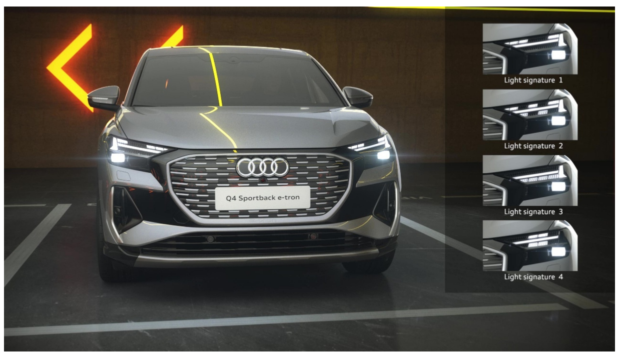

Figure 9: Customization - Audi Q4 - 2021 - Audi Mediacenter

Without this technological step, the design trends we know today, would probably not have existed. In addition to changing the general design and details of our vehicles, this step can be also considered as the first level of a more evolved type of communication, increasing accuracy and relevancy of the messages delivered to other road users.

Today, the emergence of display technologies opens a new era that will allow ever-advanced communication. Display integration may create new impacts on style, depending on selected technology. It is also a great opportunity thanks to the awesome possibilities offered by the display itself through the images displayed.

4.2 Specific style impacts

First design key : Curvature

The stylist's dream of having a full free form display matching with bodywork, as demonstrated with the Audi Swarm study shown in 2013 (figure 10) is still far from being mature for production today.

Figure 10 : Audi Swarm - 2013 - Audi Mediacenter

If curved display technologies progressively emerges in the consumer market, shapes remain ruled and not fully free form. In addition, specific reliability constraints limit curvature threshold to flat or slightly curved shapes. This impacts the style of surfaces and volumes, as experienced with OLEDs, by using floating 3D elements or by faceting displays bricks when the designer seeks to follow a main volume.

Secund design key : Sizing

The beginning of the decade has seen a strong styling trend to refine signatures of front and rear fascia with increasingly reduced heights. This height reduction seems part of a trend to emphasise the minimalist and pure graphic signatures while demonstrating how new technologies such as LEDs and Laser are able to take up challenges of maintaining legal specifications with ultra homogeneous thin aperture.

Optimised Added Value of exterior display requires to consider all use cases including communication use cases where a large surface is required to ensure good understanding of message as stated above.

Therefore, Display sizing for long distance and resulting display height will be one of the important data to be taken into account by the designers, to integrate it suitably into their design, while display width should have less impact considering current trends.

Thirds design key : Location

Location of the display on the car is also a key element. Location on centre of fascias, two symmetrical displays disposed on each side on fascias, but also display located on car side are three options that need to be considered according to the use case i.e. according to the relative position of the viewer with the car. Figure 11 provides a good illustration of how the location of the Display on the front side is linked to viewer position and how this position modifies the display perception due to Car body shape.

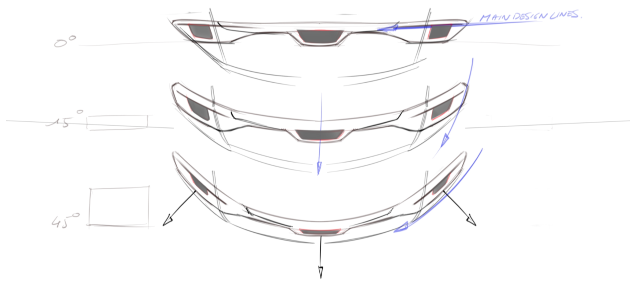

Figure 11: Front location - Valeo Design

Mastering the design

The compatibility of these 3 design keys with a mastered style harmoniously matching with car body and headlamp design rely on flexibility offered by display technology: especially on free form contour - as illustrated on Figure 12.

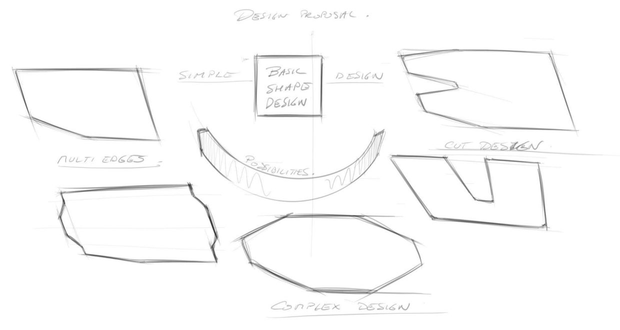

Figure 12 - Front location - Valeo Design

Current display flexibility, and also future flexibility offered by technology improvements are key, but in any case, successful harmonious style requires that display integration takes place as early as possible within the car development process, as illustrated in figure 13:

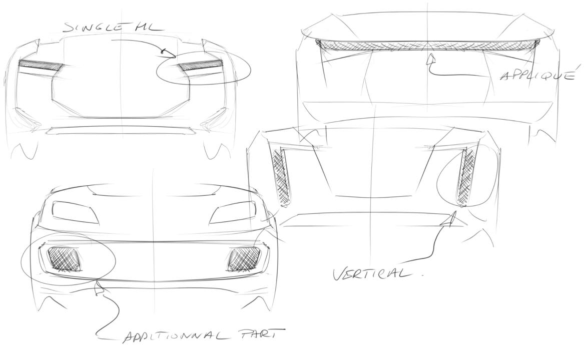

Figure 13: Front location - Valeo Design

4.2 Display content

If regulatory constraints are limiting display content, especially the colour, the animation and activation rules, there is still some room to create awesome possibilities of contents to offer customised signalling functions. The use of grayscale to create a 3D effect is a good example of what can be done as illustrated in figure 14.

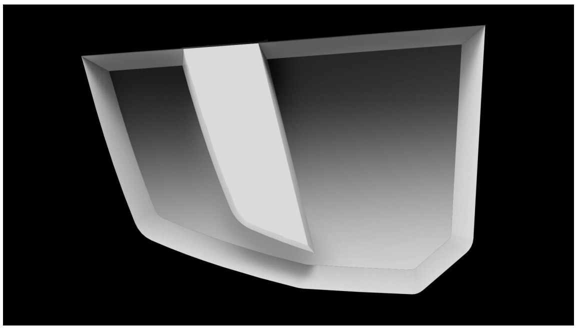

Figure 14 - Sample of 3D effect - Valeo Design

Animations are possible in the context of leaving home scenarios without impairing road safety. All these contents require the development of a new domain inside the exterior light design departements, opening an evolution of designers know-how and designers tools that are closely linked with 2D or 3D animation world, and this evolution will increase driving experiences and interactivity for end users.

4.3 New Possibilities

Several design proposals have been presented on concept cars in the last decade, revealing the need to communicate and highlighting the "hype" of hyper connectivity and keeping up with the pace of the society/generation.

Most of these proposals conceal a consumer display under a smoky cover. This approach shows the use cases and functionalities but it is not sufficient to provide an harmonious and automotive robust design. Despite today's limitations of display technologies, a first step will initiate the revolution that will arrive in the more distant future with much deeper impacts on future vehicles. The Fun Vii prospective concept (Figure 15) made by Toyota in 2011 already showed some of these new possibilities and design impacts. Now, it is to the design studios to exploit all the new features and characteristics to propose their visions of the communication based on the displays.

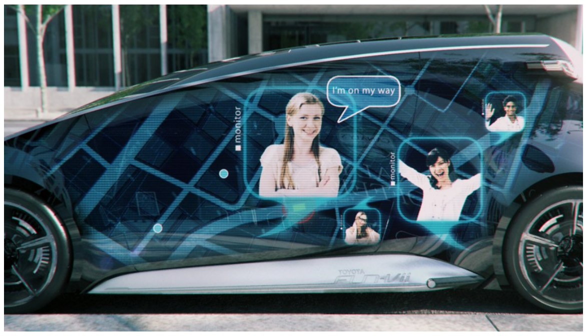

figure 15 - Toyota Fun VII - 2011 - Toyota Press Site

5. Integration and Visibility

As explained above, Visibility relies on contrast between L_{ON} and L_{OFF} areas. Majority of L_{OFF} contribution is linked to the reflection due to exterior light surrounding the car's environment: Sky by day, Street lights or Headlamps of oncoming drivers by night. This contribution is by far much higher in comparison to potential crosstalk effects that may be observed in some display technologies. Figure 14 clearly shows some of these effect also called "Phantom effect"

Figure 16: Phantom effect on Rear Lamp

Considering brightness coming from exterior light (L_{ext}), We can easily specify required display brightness to ensure good visibility:

$$L_{ON} = L_{ext} + L_{display} \qquad [2]$$

$$L_{OFF} = L_{ext}$$

thus : $L_{display} = C_w.L_{ext}$ [3]

Beside required contrast, Brightness specification depends on exterior light configuration but also on the way light is distributed by the Headlamp, the Rearlamp or central module. Reduction of these effects maintains good visibility while having a huge impact on cost and power consumption. We present here 2 key design factors having significant effect on Brightness specification.

5.1 Outer lens

Vitreous Reflection on outer lens is a strong contributor to Background brightness and some relevant design choices are preferred. Anti reflection coating but also matching between outer lens and display colour is a good way to reduce Brightness reflected by outer lens. Figure 17 shows Brightness specification by day considering a large sky area with high turbidity providing a brightness of 15 kcd/m².

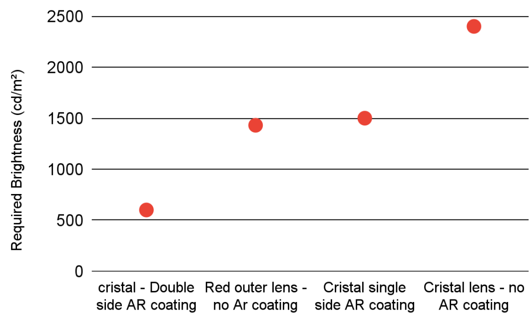

Figure 17: Brightness request according to lens design

If the added value of AR coating is obvious, the use of a red outer lens provides a huge benefit. For rear red display, this option is efficient and remains quite cost effective.

Inclination of the outer lens is also a key design factor having an impact on specified brightness. Lower inclination reduces by far the statistical chance that the viewer sees an image of sky reflected by the outer lens since sky areas toward low angular height are hidden by all objects surrounding the roads and streets: trees, walls or buildings. This is clearly illustrated by Figure 18 showing cars in the same environment. In the upper image, outer lens has an inclination of 5° whereas outer lens of lower image has an inclination of 30°.

Figure 18: impact of outer lens inclination on contrast and required Brightness

5.2 Veiling Luminance and Disability glare

Brightness Specification must also consider glare effects coming from various sources. Other functions located in the rear lamp (STOP, Turn) or in the headlamp (DRL, Turn, Low Beam) are obviously to be considered, but Some style objects such as bezels or even the car body itself may create disability with reduction of Contrast. A concrete example is observed in figure 19 showing required brightness according to distance between various glare source and display. Veiling Luminance is evaluated using CIE 2002 standard formula which is known as being valid for short angle value. Viewer is placed at 10 m and is 60 years old.

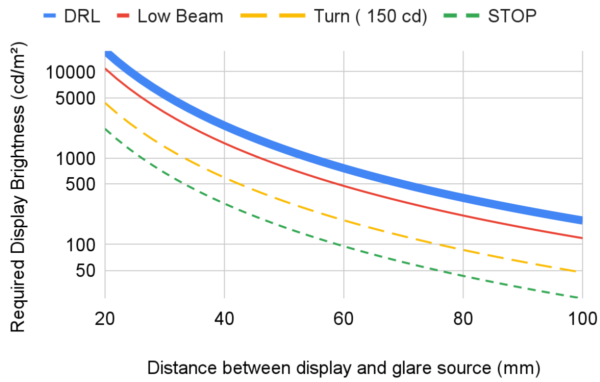

Figure 19: Brightness specification with various glare source

As clearly observed in the graph, the contribution of veiling Luminance cannot be neglected, but more than that it shows how smart integration that limits veiling luminance can avoid specification of High brightness and thus - avoid High power consumption.

7. Integration and Electronic Systems

Each car maker or group has their own platform for their different models. This leads to a huge diversity of System architectures. Moreover, The fast evolution of the different platforms with different protocols and communication buses (CAN, FPDLINK, RGB24, Ethernet…) requires a strong knowledge of the vehicle architecture and customer, in order to give the best performance.

To face high variety and fast evolution, Two Architectures are able to drive the display and control image of high definition: Driver Module can be seen as a “Player” or as a “Streamer”, as illustrated in figure 20 which presents a diagram for the 2 options.

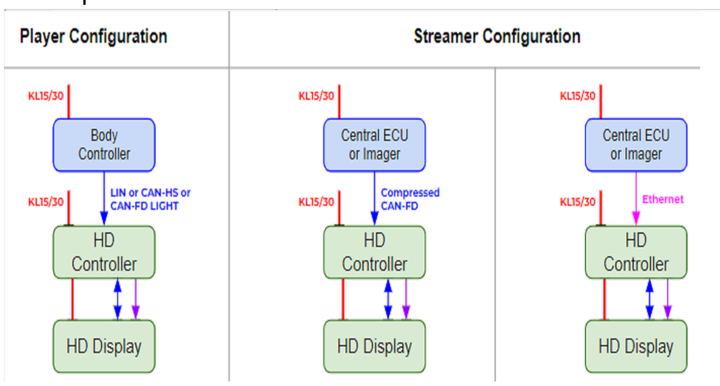

Figure 20: HD Module Vehicle architecture options

Player mode

As a “Player”, the display module corresponding to the display itself and its controller stores various Images or Animations (“bank images”). When the vehicle sends a request to the module according to the driving use case and scenarios, the module answers to the request by displaying the expected Image, Animation or Video. Player mode allows fast transfert of the request without impacting vehicle system architecture: The use of classical CAN bus remains possible.

Streamer mode

In “Streamer” mode, “bank Images” are stored in the vehicle ECU. Therefore, ECU transfers the image to the display module which directly displays the required image. This version has a strong need for data bandwidth requiring different solutions such as Ethernet bus or a traditional CAN FD if data is compressed. However, Ethernet protocol is more and more used and will become the standard communication bus in the next vehicle platform generation.

This “bank” of images/videos/animations can be loaded and updated by the car maker through OTA (``Over-the-Air”) or by the vehicle owner through his smartphone. The owner is able to select from the library (defined by the car maker) the different options for each use case such as a personalized signature of the vehicle. In the same way, a company owning a vehicle fleet would be able to apply standard personnalisation on all cars. Both are challenging solutions for which Valeo has developed strong solutions and Tools.

Thanks to years of expertise and strong investments in this field, each element is being designed & defined taking into account performance, cost and CO2 neutrality.

7. Display Technologies

In the consumer display world, high competition but also a high variety of needs and applications lead to a high variety of technologies. Development of display for exterior automotive application requires a rigorous selection of the technologies in two steps: First step is to identify the key criterias that are used to select the technology. Second step is the evaluation of the technologies and their roadmap

7.1 Identification of key criteria

For any systems dedicated to automotive business, several constraints criteria must be considered corresponding to key following criterias:

Light Efficiency

This criteria is inevitable in the current context of CO2 reduction,and is emphasised in the context where visibility by day required relative high brightness

Cost

Cost is obviously an important factor but it should be considered cautiously as regard as added value of the product, and as regard as car segmentation.

In addition to these criteria, we also must consider specific criteria relative to the Display Application and to display integration.

Brightness

As observed in the previous page, Visibility by day is key to ensure good visibility. Even if some smart integration helps to decrease specification, Required brightness remains higher in comparison to display used in the consumer Business.

Style Flexibility

As seen above, mastered design relies on display flexibility: free form edge and curvature are therefore to be taken in account.

Scalability

Scalability is the ability to tune LED pitch, colour and display size. This is very important when willing to easily adapt the technology to the needs requested by customers.

7.2 Technologies

We can make a distinction between self-emissive technologies and technologies requiring light modulation.

Self Emissive Technologies

LEDs & OLEDs are the two light source technologies used to build self emissive displays. Two typical kinds of LEDs are used: MiniLEDs above 100µm are associated with Passive matrix drivers whereas MicroLEDs below 100µm are usually used with active matrix drivers to maintain good brightness. Last but not least, OLED is associated with a thin film active driver to build AMOLED. Figure 21 presents radar mapping of these 3 technologies relatively to the 5 key criteria presented above, and considering performances reached today.

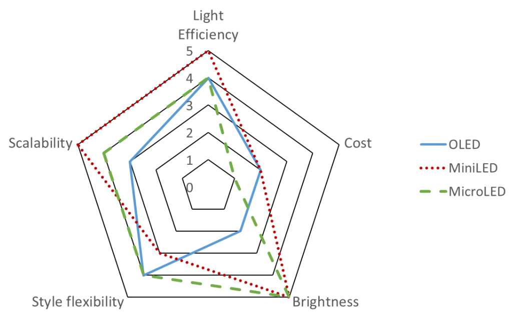

Figure 21 : Ranking of Self emissive technologies

Technologies with Light Modulation

LCD is the most common technology to modulate the light thanks to polarised light. Recent improvements have been made possible with Mini LED by using local dimming of back lighting illumination, thus reducing power consumption and crosstalk effects. Figure 22 shows radar mapping of the two existing LCD technologies: Standard Technology without local dimming, and standard technology with local dimming.

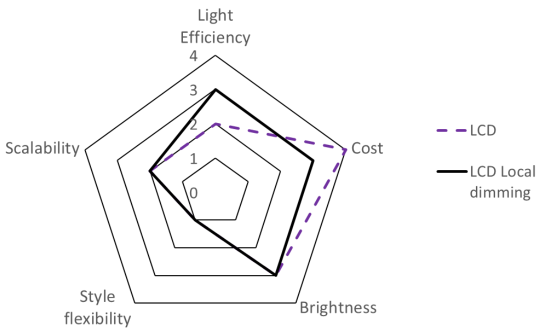

Figure 22 : Ranking of LCD technologies

As clearly observed on these graphs, Some technologies such as MiniLED and MicroLED are very promising since they can provide both good brightness and good efficiency. Moreover, these solutions are quite flexible. If Cost is High today, we can expect a decrease in the future thanks to the volume effect. Moreover, scalability through pitch and size gives the possibility to tune the compromise between cost and pitch and address a large panel of car segmentation.

8. Conclusion

Exterior display is the next step of digitalization and beyond continuing to shape the style of the vehicle. It will bring new usage for communication pushed by the automation of the vehicle where the regulation must continue to evolve to open these new possibilities.

As we can see in this paper, once the right display technology is selected, the key activities are its integration on the vehicle. Based on a full system approach from the analysis of the use cases down to reliability tests, Valeo develops all the technical solutions for display integration whilst mastering the impact on the style of the vehicle, the compliance with the electronic architecture and ensuring its visibility on the vehicle whatever the exterior light surrounding the car's environment.

All aspects of these developments are also driven by the VALEO commitment to reach carbon neutrality by 2050.

In the context of the EU Hi-Drive collaborative project, the display implementation and the relevant use cases will be tested in real conditions. These tests will contribute to understand the needs of other road users interacting with autonomous vehicles in order to increase acceptance

9. Acknowledgement

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11. Glossary

eHMI : external Human-Machine Interface

EU : European Union

AR : Anti Reflection

AV : Automated Vehicles

ODD : Operational Design Domain

C2P : Car to Pedestrian

LCD : Liquid Crystal Display

LED : Light-Emitting Diode

AMOLED : Active Matrix Light-Emitting Diode

OLED : Organic Light-Emitting Diodes

OTA : Over The Air

CAN : Controller Area Network

CIE : Commission Internationale de l´Eclairage

SAE : Society of Automotive Engineers

DRL : Day Running Light

HD : High Definition