

Rear Lamps

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In December 2020, Geoff resigned after 12 years as GTB President. He is now an Independent International Regulatory Advisor and Driving Vision News Senior Regulatory Advisor. Additionally, Geoff continues as Honorary President of the ALE Forum (China) and is a member of the IFAL Advisory Board (China).

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In 2008, he initiated the launch of his own company, Driving Vision News, which has become the automotive lighting and driver assistance industry's journal of record dedicated to keeping the community informed and communicating about the latest progress and developments.

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Daniel Stern, DVN's Chief Editor based in Vancouver, BC, Canada, is considered by DVN President Hector Fratty as one of the five greatest lighting experts in North America. He is an appointed member of the US transportation Research Board Visibility Committee, which steers North America research on matters related to automotive conspicuity, lighting performance and regulation. He is an active member of the SAE Lighting Systems Group, and attends and participates in the world's automotive symposia and technical conferences.

About Driving Vision News

DVN is the vehicle lighting and ADAS industry's journal of record, dedicated to keeping the community informed and communicating about the latest progress and developments.

DVN's three pillars are:

- **Technological watch** with weekly news, analysis, and crucial information on innovation and ongoing developments in lighting, ADAS, and related matters; there are also monthly deep-dive reports and quarterly brief reports with sharp focus on cutting edge technologies, company profiles, regulatory matters, and other relevant content available only from DVN.
- **Networking** of high-level decisionmakers, researchers, innovators, practitioners, academics, and regulators to make new business connections with two workshops per year in rotating locations throughout America, Europe, China, Japan, India, and Korea. DVN Workshops gather over 300 participants.
- **Promotion** of DVN's member companies, numbering at least 150. We facilitate the knowledge, recognition, and application of innovation, which in turn paves the way for commercialisation, enabling to build new relationships through DVN Community to forge new business worldwide. The DVN Gold membership roster includes 30 automakers, 30 lighting & ADAS tier-1 suppliers, 15 light source suppliers, 50 tier-2 & -3 suppliers, and a wide variety of universities, research outfits, and consultants. DVN Gold members receive all publications and attendance privileges at all DVN Workshops. Basic members—2,500 and counting—receive Newsletters and can obtain access to other DVN publications and functions.

Table of contents

1 · Executive Summary.....	p.1
2 · Introduction.....	p2
3 · History.....	p3
4 · Rear light functions.....	p11
4.1 Safety	
4.2 Design and style	
4.3 New functions for communication	
4.4 Invisible design constraints	
5 · Safety: regulation for rear lamps.....	p13
5.1 Regulations	
5.2 Status of innovation under consideration by regulators	
5.3 Activities to remove regulatory barriers to innovation	
5.4 Outlook	
6 · Style: Demands and trends.....	p19
7 · Technologies for traditional functions.....	p25
7.1 Incandescent bulbs	
7.2 LEDs	
7.3 OLEDs	
7.4 Animation with rear lamps	
7.5 Mechanical structure of rear lamps	
7.6 Electronic Control	
8 · Technologies for new functions.....	p42
8.1 Displays	
8.2 Projection	
8.3 Integrated sensors	
9 · Conclusion.....	p45

1 · Executive Summary

Rear lamps have existed since very shortly after the dawn of the automobile. The first ones, like the cars they were attached to, were basic and addressed the need for nighttime conspicuity in a primitive manner. Safety functions were progressively improved by adding new functions—reverse light, rear fog light—and more stringent requirements for the basic functions: larger lit areas, wider distributions of light, higher intensities. The introduction of LEDs with instant-on illumination and more stabilized beam has carried this trend forward. Regulation has also evolved to allow and then require high-mounted auxiliary stop lamps, emergency braking display, hazard warnings, and other suchlike. The still-optional adaptive rear-light systems seek to improve safety performance in difficult conditions.

Besides this important role for safety, rear lamps are currently considered as a priority design feature, and more precisely the most important element at the rear to express the signature of the car. Design has in fact been the real engine for innovations at the rear in recent years and this will likely continue in the future.

Before the arrival of LEDs, the challenge was steep to be original. Bulb technology imposed severe design constraints. Nevertheless, engineers and designers are innovative, and figured out ways to have very homogeneous lit surface, a variety of unlit appearances (sometimes with colours totally different to those of the emitted light), perfect fit and finish, and other innovations with optical systems using reflectors, fresnel lenses, coloured internal filters, multicolour injection, new welding techniques, and other complex processes to fulfil these needs and wants.

The introduction of LEDs opened the gates to boundless opportunities by dint of compactness, low operating temperatures, pure colour, and the freedom to use as many LEDs as wished. One of the most important new techniques is the light guide, either by tube or by surface, with so many abilities to produce thin, long, or decorated elements. OLEDs recently joined in as an interesting addition, bringing new prospects for illuminated facets.

Thanks to this large spectrum of technical possibilities, the current trends from designers demands are orientated to thin lights, full-width rear lamps, illuminated logos, precise internal decorations, and displaylike appearance.

Above all, the demand is to express a signature, and the tail function is the cornerstone for that specific function—whether or not the lamp is lit.

Animated light is another trend requested both by design and marketing. It is applied for turn indicators with a wiping effect, and more and more for numerous kinds of welcome scenarios profiting from the tolerance of regulation when the car is stopped.

In the foreseeable future, rear lamps play a central role in innovations for safer and more connected vehicles: rear lamps with displays, with road projection, perhaps with LiFi, will progressively morph from conspicuity devices to versatile communication tools, with the ability to provide granular messages to relevant traffic participants, including more and more autonomous vehicles.

Rear lamps occupy two of a vehicle's four strategic corners, and sensors including cameras and radars will likely be increasingly integrated into rear lamps to offer optimal field of view and detection aptitude.

So, the future of rear lamps will prioritise style with unfettered imagination, while at the same time realising long-awaited features to enhance functional safety.

2 · Introduction

Rear lamps are often somewhat overshadowed by headlamps and their exceptional palette of flashy technologies. Nevertheless, rear lamps are crucial to safety, and have increasingly become the cornerstone for the style at the rear. During nighttime, in fact, the rear lamps are by far the main image of what people see as the car.

Brand signature advertising is increasingly a function unto itself, and rear lamps are the main device at the rear to delivering it, often now in concert with the DRL/position lights at the front of the vehicle.

In this report, after presenting an illustrated history of how we got where we are now, we shall analyse the functions of rear lamps, the traditional conspicuity functions, and also the relatively new major role for style, as well as the future involvement for communications.

Functional style will be discussed in detail, showing various realisations of current trends.

We shall also describe the technologies necessary to achieve these functions in traditional rear lamps—the former ones with bulbs, and the new one with LEDs—and the ways to achieve the mechanical structure of these devices.

New technologies are described for future communication functions, particularly displays, projection systems, and specific ADAS sensors that can be integrated, and we'll go into some detail on the work under way to bring those functions to the world's roads.

The target of this report is to show that even if rear lamps are not historically the primary main object of interest in vehicle lighting, it is a very quickly evolving domain with more and more high-tech products, and a very important one for style, signature, and safety.

3 · History

3.1 Evolving Design and Style

The first automobile rear lamps were inspired by the nautical navigation lights and railway safety lights. Boats show a red light to port (left side) and a green light to starboard (right side). These navigation lights are to allow for the right-of-way priority system to work after dark: as a boat operator you have the right of way over boats to your left; they see a red light on your boat telling them to stop. Boats on your right have the right of way over you; they see a green light on your boat telling them they may proceed.

Railroad marker lamps were placed on the caboose or the rearmost car of the train. Like boats, they used red and green lenses to facilitate right-of-way decisions: red light was shown to the rear when the train was on a main track, to advise approaching trains the space ahead of them was occupied. Green light was shown to the rear when the train was on a siding adjacent to the main track, to advise approaching trains there was another train, but it was not in their travel path.

Rear lamps on cars in the horseless-carriage era through the mid-1920s, too, used red and green light in ways analogous to the nautical and railway practices: a red lens faced the rear, and a green lens faced to the left—the idea being to advertise the vehicle's direction of travel (an early forerunner of American-style side marker lights!). However, unlike the railway and nautical lighting conventions, there were no uniform standards for car lighting. This passage from the March 1902 'Motor Review' publication gives a glimpse of the extreme regionality of early vehicle lighting practice.

to promote contests to demonstrate exactly what 12, 15, 20, 25 and 30 miles an hour actually represent in the way of speed. Under existing conditions there can be but slight hope for equitable enforcement of such speed laws as experience has proved necessary."—*Editorial*.

The use of a **green lens** for the left-hand lamp of an automobile is meeting with favor in Boston, as it tells pedestrians in what direction the machine is going.

—

Acetylene Generators Described—In a 100-page pamphlet published by *Office Central de l'Acétylène*, Paris, which represents the united acetylene interests of France, descriptions and drawings are given of about 30 acetylene generators which have been proved reliable in practice. The illustrations show the



Early horseless-carriage tail lamps, like the headlamps, burned lamp oil (purified kerosene/paraffin) or acetylene. The first electric rear lamps appeared in 1915. Although some of these lamps were quite ornate in their styling, functionally they were quite basic, with no real photometric engineering or intent beyond *light of this colour in that direction*. By the mid-1920s, the beginnings of intentional beam design appeared, and brake-activated stop lamps were offered as add-on accessories.



1923-'27 Ford Model T oil-burning tail/licence lamp: green to the left, red to the rear, white to the licence plate →



← *Accessory add-on stop light on 1923 Buick*

Before World War II, rear lamps began to evolve. They were still simple, but began to take on shapes adapted to the body of the car and with a chrome bezel, as seen on the Citroën Traction Avant—which also used separate high-mounted turn signals. Turn signals followed their own evolutionary path; while the flashing type we know today took root in America, another type was widely used in Europe, the UK, and Japan. They consisted of a semaphore with a light at the outboard end. The semaphore would unfold from the relevant side of the car to indicate a turn in that direction. In Britain these were called Trafficators.

*Trafficator activated on 1954
Armstrong Siddeley Sapphire ↓*



*1954 Citroën Traction Avant →
stop-tail (low); turn signal (high)*



In the 1950s, particularly in America where headlamps were rigidly standardised, rear lamps were often flamboyant—sometimes even styled in a rocketlike manner, reflecting the space-age exuberance and cold-war preoccupation in design of that time.

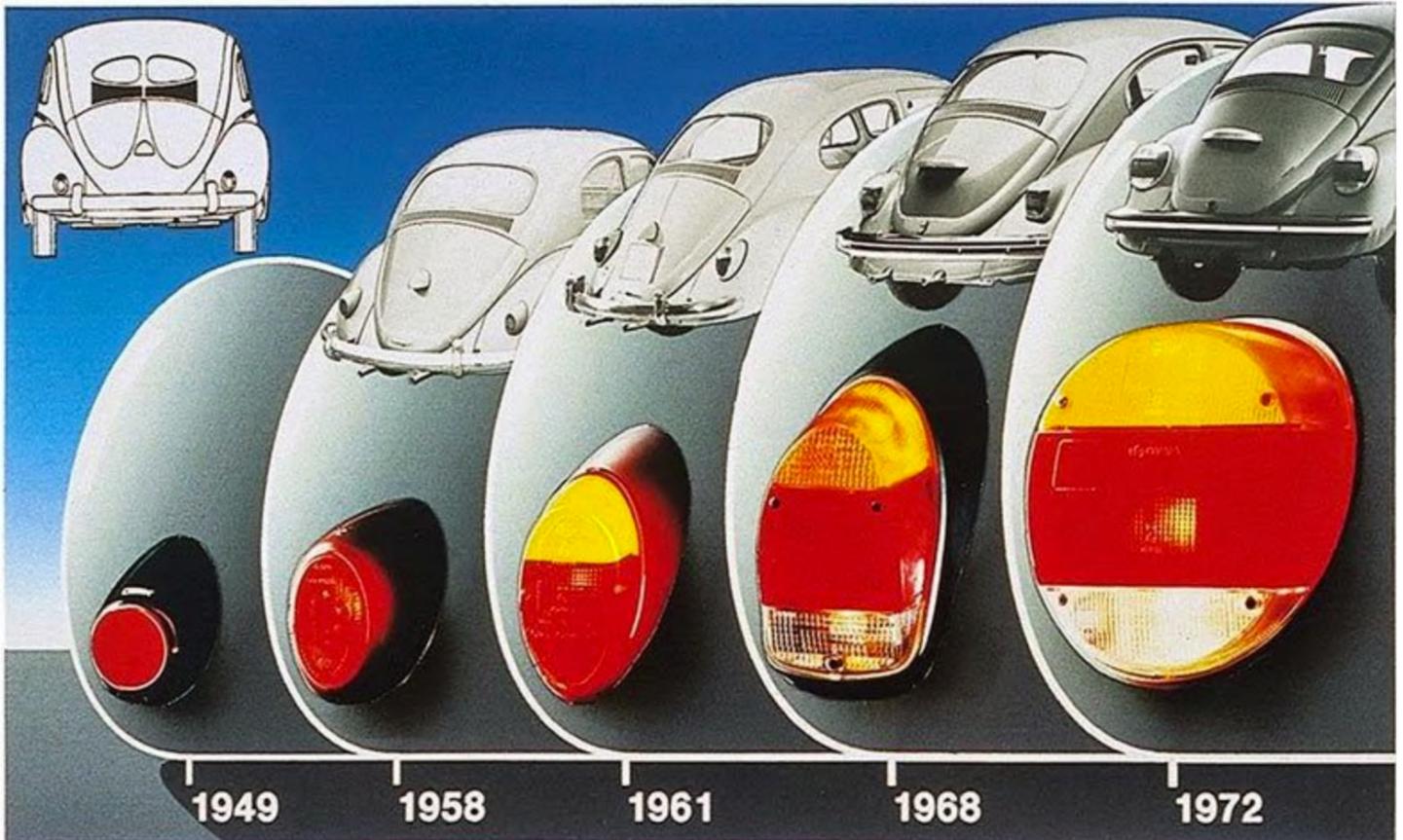
← *1959 Cadillac Eldorado*

As the fins and chrome of the late '50s gave way to less overtly ostentatious designs, rear lights carried on growing more integral to the overall design of the car. Front lighting was still severely constrained in design as all vehicles in America still had to use round sealed beams in one of two sizes, so rear lamps carried the majority of lighting design expression.

1961 Chrysler Valiant →

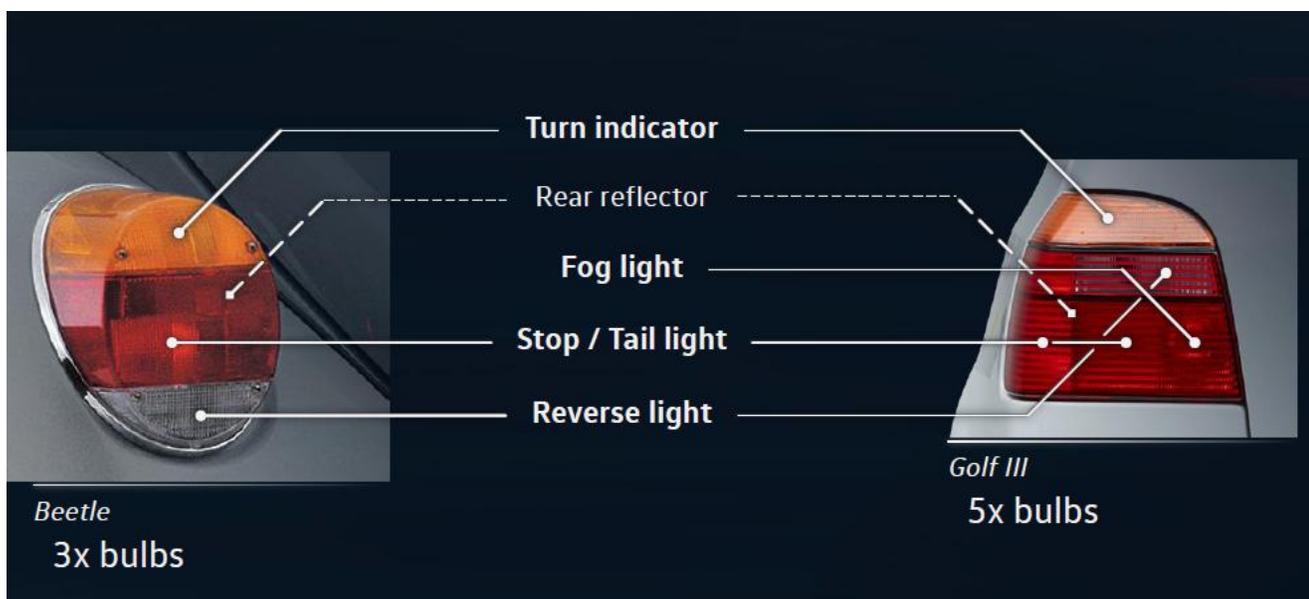


Traffic speeds grew faster and regulations began to impose progressively more stringent requirements and constraints on the design and performance of rear lamps. Cars sold worldwide over a period of many years, such as the VW Beetle, clearly illustrate the resultant design trends:



Volkswagen Beetle rear lamp design evolution overview (image: Hella)

From the 1960s to the 1990s, the list of rear lighting functions grew to its present state—the rear fog lamp was the last one to be mandated in the UN Regulations, in 1991. Over the same timeframe, rear lamps become much more integrated into the the bodywork, as illustrated by this comparison of the final-design 1972 VW Beetle and the 1991 VW Golf III:





Through the 1980s and '90s, the basic concept remained the same: a box made of two or three colours of plastic, with a handful of incandescent bulbs inside. There was strong demand for breakthrough styling, but the incandescent technology exerted fairly tight design constraints. Still, there were some successful styling innovations, such as stacked subtractive filtration to obtain the required red, amber, and white light colours



with a silver, black, all-red, or even blue or green unlit appearance. (images: Hella)

Escape from the incandescent bulb's design constraints on rear lamps began with the introduction of LEDs toward the end of the 1990s. With the possibility to use arrays or matrices of numerous light sources, to have light guides and very compact optical systems, designers obtained a grand new level of freedom and flexibility, with consequently a myriad of possibilities.

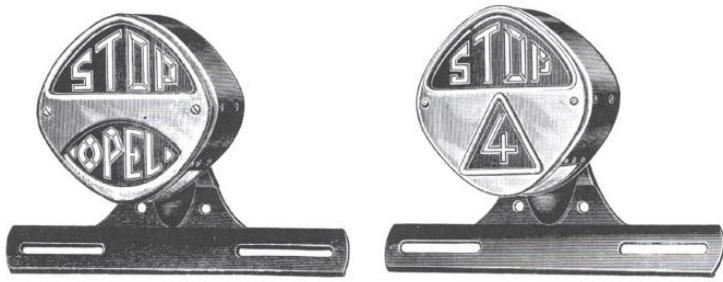


Evolution of VW Golf rear lamp design with LEDs

3.2 Evolution of rear light functions

At the beginning of the 20th century, the first need was to illuminate the licence plate, and often, a part of this light was directed to the back of the car with a red lens creating a position (tail) lamp. The first requirements for tail lamps appeared in the 1920s, closely followed by rear retro-reflectors, and these requirements were more or less uniform by the 1950s.

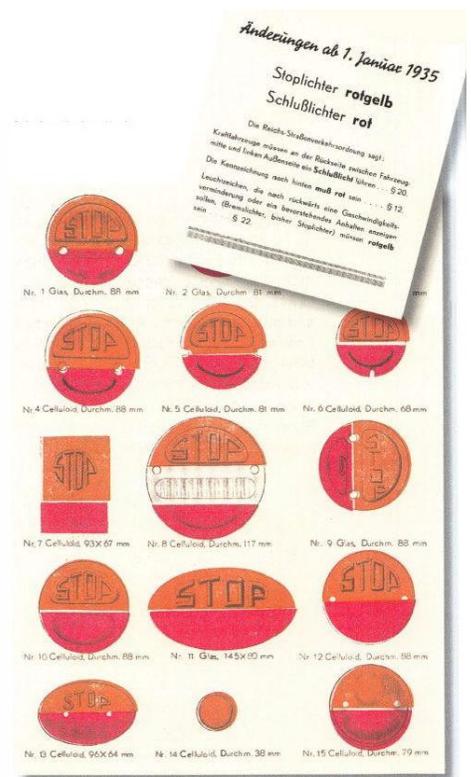
The first stop brake lamps appeared as early as 1905 as add-on accessories, and remained largely as such for several decades—as illustrated by the accessory stop light on a 1923 Buick shown in the previous section of this report. Regulations were patchy and disparate until the 1960s; until then, there was quite a bit of variety

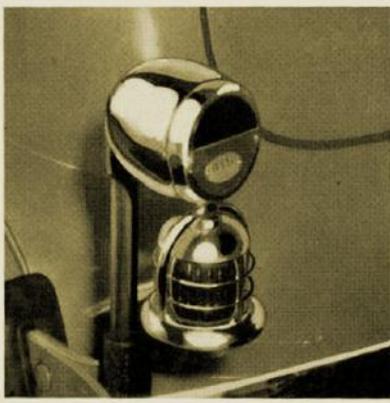


in how the stop signal was conveyed. Some of the solutions were quite innovative—and even uncannily predictive. One of the two accessory electric stop light/registration plate brackets shown here, offered by Hella in 1926, show automaker branding (Opel) on the lamp, which today is a strong trend. The other 1926 lamp shows the numeral 4, signifying a vehicle with 4-

wheel brakes and therefore shorter-than-normal stopping distances—a distant forerunner of today's emergency stop signal, which also signifies shorter-than-normal stopping distances. Some early ideas persisted for a surprisingly long time; for example, a 1935 German regulation called for red tail lights and orange (amber) stop lights. This may have been an effort at greater conspicuity by dint of a brighter appearance due to greater transmissivity of an amber lens versus a red one. Amber remained a permissible colour for stop lights under the American SAE standards, and in some U.S. state statutes, until surprisingly late: well into the 1970s! In practice, though, amber stop lights were seldom seen except on very old European cars; the red-means-stop convention took strong hold early on.

Another innovative and fantastically predictive stop light idea took the form of a swinging stop light offered in the mid-1930s. It was operated by engine vacuum in the same manner as the windshield wiper motors of the day; when the driver would step on the brake, the bulb would light up and the lamp would wag back and forth like a swinging railcar





Studebaker Wig-Wag Signal Light

This is a new and novel signalling device which will have a wide appeal to Studebaker owners. In operation it simulates a swinging railroad lantern and is therefore a most effective warning signal since it is an established fact that a light in motion commands attention more effectively than a fixed signal.

Adaptable not only to the 1936 Studebakers but to prior models as well. It mounts on the rear bumper at the left and is set in operation by foot brake pedal pressure (vacuum operated).

All necessary attaching parts and full instructions covering simple installation are included with each signal.

Installed List Net Price
Including Tax Uninstalled

AC 370 Studebaker Wig-Wag Signal Light \$10.00 *\$5.50

*Factory installation \$1.00.

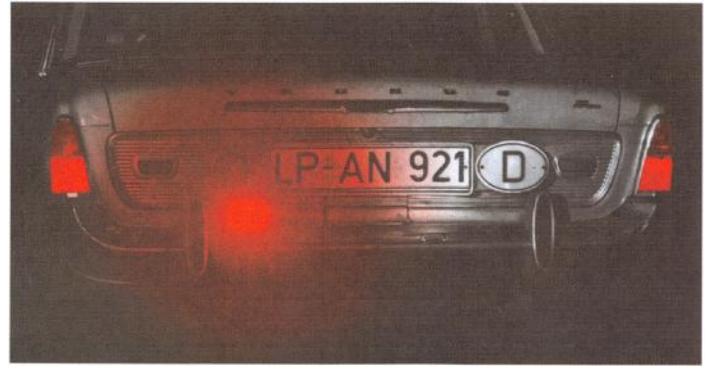
Lantern swings when brake pedal is depressed

lantern, drawing other drivers' attention to the stop signal, as seen in [this video](#) and [this one](#). It is not difficult to draw a conceptual line from this to today's progressive turn signals! The \$10 installed price is about USD \$200 in today's money.

The first turn signals appeared in the 1920s. First requirements were established in Europe and in the US in the 1930s; the US preferred flashing systems, while Europe and Japan first went with the semaphores described earlier. The flashing system won out by the 1960s and is now universal, though colour still is not fully standardised—everywhere in the world legislated for amber turn signals by the early 1970s, except the US (and, perforce, Canada and Mexico) where the rear signals can still to this day be red.

The other rear lighting functions were introduced significantly later. Generally, they were introduced as options—allowed and regulated, but not required—and then became mandatory.

Rear fog lamps, extra-bright tail lights to improve conspicuity of vehicles in bad weather, were first introduced in 1966 under German national approval, as shown here on a Ford Taunus. The first pan-European regulation came in 1974, making them permitted throughout the bloc, but they were not required in Europe until 1990. In America they still remain permitted but not required; they are not widely fitted there (and even less widely understood).



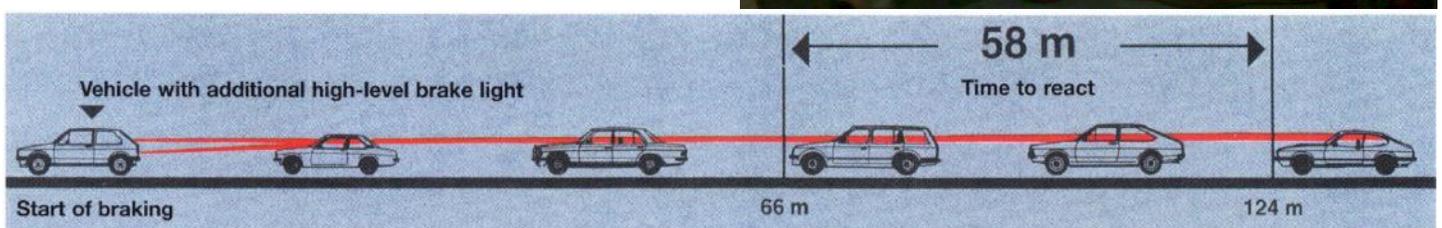
Reversing lamps appeared in America in the 1920s. They became effectively mandatory on 1966-model vehicles: Still absent any Federal vehicle equipment requirements, reversing lamps were included on a list of features required on vehicles purchased by the U.S. Government. Automakers didn't want to lose out on the prospect of lucrative government fleet sales, so the lamps moved off the options list and became standard equipment. When Federal Motor Vehicle Safety Standards came in for 1968, reversing lamps became officially mandatory. Some countries permitted reversing lamps to emit white, yellow, or amber light; this led to the implementation of amber combination turn/reverse lamps. These functioned comparably to the American red combination turn/stop lamp, as shown in [this video](#). These



were a common setup in Australia and New Zealand into the 1980s, where authorisation was finally ended with the 1995 models.

There was sporadic interest in high-level auxiliary stop lamps starting in the late 1960s, standard equipment on this 1973 Oldsmobile; a similar extra pair of stop/turn lights was offered as optional equipment on the 1968-'70 Ford Thunderbird (\$34 then = \$244 now; fewer than 100 cars are estimated to have been equipped). Then there were efforts

in Germany along the same line: dual (left/right) high-level stop lights, as shown here on a 1972 BMW 2002. The single central high-mounted stop lamp (CHMSL) as we know it today became mandatory in the US and Canada in 1986, authorised in Europe in 1993, and mandatory from 1998. It improves the stop signal by making it visible to drivers whose view of the vehicle's left and right stop lamps is blocked by interceding vehicles. It also provides a redundant stop light signal in the event of a stop lamp malfunction. In North America where rear turn signals are permitted to be red, the CHMSL also helps to disambiguate brake lights from turn signals, if at least two of the car's threelamps can be seen simultaneously.



For more details about the history of rear lamps, refer to a 1999 UMTRI paper: [HISTORICAL DEVELOPMENT AND CURRENT EFFECTIVENESS OF REAR LIGHTING SYSTEMS](#) (pdf)

3.3 Light source evolution

From just after the brief oil/acetylene era until the late 1990s, and still in many vehicles—even new ones—on the roads today, the rear lighting functions are provided by incandescent bulbs. For many years, most all bulbs had a metal bayonet (push/twist) base—usually made of plain brass on American bulbs; nickel-plated for increased corrosion resistance on European and Japanese bulbs. IEC standardisation of bulb bases and auto electrical systems evolving in parallel all round the world resulted in closely comparable bulbs being developed and standardised by European, American, and Japanese industry.



Top, left to right: 1157 (like P21/5W) • 3157 (like P27/7W) • 3157NA (like PY27/7W; amber light)
Middle: PR21W (red light) • W21/5W (like 7443) • WY21W variant (amber light with chrome unlit effect)
Bottom: PY21W variant (amber light with iridescent blue-green unlit effect)

In an effort to ease assembly line installation of bulbs, American industry devised new bulbs for use in rear lights in the late 1980s. These have a plastic wedge base. The concept was further refined by Japanese industry in the 1990s: one-piece, all-glass wedge-base bulbs. Regardless of base type and national origin, more or less all the different bulb designs are recognised by regulations and standards worldwide.

Each bulb has one or two filaments; the 2-filament types provide a high-wattage, high-intensity function such as a stop light or rear fog light as well as a low-wattage, low-intensity function (tail/rear position light) from the one bulb. The bulb glass may be coloured to provide amber or red light, or it may be colourless, in which case the lamp itself must provide the filtration to tint the light as required for the various functions. Design variants to camouflage the coloured bulb when unlit were commercialised starting in the late 1990s. Over the years, variants have proliferated of the relatively few basic bulb types—especially in America where signal bulbs are not regulated. Different wattages and outputs, different lifespans and colours...some of the differences seem quite minor (such as the slight difference in dim-filament output between a P21/5W or 1157 and a P21/4W or 2057), but these differences can be crucial to the functional compliance of the lamp they're installed in.

In the 1990s, some automakers began phasing out 2-filament bulbs; instead, they feed a single-filament bulb with PWM: lower effective voltage for the dim function; higher for the bright function. This reduced socket complexity, bulb cost, and eliminated one wire to the bulb, and brought the benefit of faster rise time for the

brake light (due to the filament already being preheated by operation at the lower tail light voltage), but these benefits were partly countered by the increased complexity of the PWM driver required.

4 · Rear light functions

4.1 Safety

Rear lamps were initially meant to provide conspicuity; that is, to make the equipped vehicle functionally visible after dark. This is still why we have rear lights in their variety of functions as regulated round the world. A core reason for rear lights is to reduce the number and severity of rear-end crashes, which are relatively numerous—about 30 per cent of all traffic crashes.

Appropriate conspicuity is not achieved at random; it requires the vehicle to be meaningfully perceptible throughout the relevant range of horizontal and vertical observation angles, so that drivers, pedestrians, and other traffic participants with higher or lower eye heights, observing from not just straight behind but from a variety of positions to the left or right, will be able to see and quickly and accurately receive the messages being sent by a vehicle's rear lights—whether the lights are clean or dirty to a reasonably predictable degree, and whether on a bright, sunny day...a dark, stormy night...or anything in between, and without glare. This last point is a difficult one; the intensities required for adequate conspicuity in bright sun would cause extreme glare at night, but limiting intensity to the values required to avoid nighttime glare results in inadequate intensity in bright daylight. Adaptive Rear-lighting Systems (ARS) with variable intensity depending on ambient light, and the apposite regulations, were devised many years ago to resolve this conflict, but very few vehicles have been equipped.

Beyond the plain conspicuity functions—the rear position (tail) light, the rear fog light, and the passive lighting provided by the rear retro-reflector, the remaining rear lighting functions advise of a change in the space occupied by the equipped vehicle relative to other vehicles; that is, a safety-critical change in the equipped vehicle's speed or direction of travel. The stop lights advertise deceleration (and by flashing or "growing" in lit area, can advertise urgent deceleration). The direction indicators advertise lateral motion (a turn or lane change), or if all of them are flashing at the same time, they serve as a hazard warning. The reversing lamps are nominally to warn of rearward motion, light the equipped driver's way, and allow the reversing camera to provide its images, but often not enough light is provided for one or both of the latter two functions.

4.2 Design and style

Medium-early in the motorcar's history—after the brass age with its gleaming polished fixtures—there were often some efforts to embellish headlamps, but largely much less effort (and money) was put into designing the rear lights. They were generally small and broadly all similar. But now, rear lamps are totally integrated in the overall style of the car, and they are receiving the same level of attention from designers as the front lights.

Virtually every automaker actively works toward original rear lamp designs to reinforce the design theme of the car, its familial continuity, and its brand identity. The rear light signature can be like the front one given by the DRLs to tie the front and rear of the vehicle together thematically, or can be totally different. One the main interests is to advertise the brand of the car at night via the rear position (tail) light signature. That's why the tail function is the primary style target: a specific shape for its signature, and detailed specifications for its texture: perfectly homogeneous illumination, or dotted or striated effects, depth effects, segmented appearances, structural designs—a wide array of design solutions to distinguish one model from all the others.

Perhaps not as much design and style effort is directed at the stop (brake) light, but it and the direction indicator also provide broad palettes for interesting designs—particularly the direction indicator, as exemplified by sequential (progressive, sweeping, wiping) dynamic animated designs.

The rear fog and reverse light functions are very seldom seen in traffic, so usually only get "table scraps" of design attention: make them as small and hidden as possible.

Fit and finish are crucial for rear lamps, as they occupy two strategic angles of the car body: they are in a position and with colours that grab the gaze of potential buyers, and of course their entire job is to draw attention to themselves. So, they must be as close as possible to perfection, both lit and unlit.

4.3 New lighting functions for communications

Lights are communication devices. Traditional lighting technology sharply limits the bandwidth; messages can be conveyed only by variance in a few parameters: on or off, bright or dim, steady or flashing, red or amber or white. That has constrained rear lighting messages to basic simplicity: "I am here in front of you", "I am slowing or stopping", "I am reversing", "I am turning or changing lanes"...and that's about it!

Now, exponential advancements in every aspect of lighting technology means rear lights are rapidly gearing up to be involved with new modes of much more granular, complex messaging. Three main new types of communication are contemplated:

- Direct line-of-sight communication to other road users as before, but enhanced with specific light shapes, colours, or frequencies—or by using displays to write more detailed messages
- Indirect line-of-sight communication by dint of road projection of existing functions (direction indicators, rear fogs, reversing lamps, stop lamps)
- LIFI communication through a standard protocol to be invented and accepted by everybody—a much more involved development project.

Most of these new functions will require new or adjusted regulations before they're allowed on the road.

4.4 Invisible design constraints

Rear lamps, like all devices, have a great many more parameters than can those readily perceptible by an observer. These are not really seen by the buyer of a car, but are nevertheless crucial to successful development and commercialisation. They can be considered the immersed part of the iceberg: a massive but invisible part of the development effort. A non-exhaustive list includes:

- Quality at 0 km, during the warranty period, and during the lifetime of the car
- Power consumption, as low as possible—especially now with EVs in ascendancy
- Packaging and mass, as minimal as possible to maximise human-usable space in the vehicle and minimise CO₂ emissions
- Production cost, as low as possible, and ease of service as required
- Good integration with the other systems of the car, both mechanically and electronically
- Good accuracy for every component and assembly to ensure a perfect fit and finish

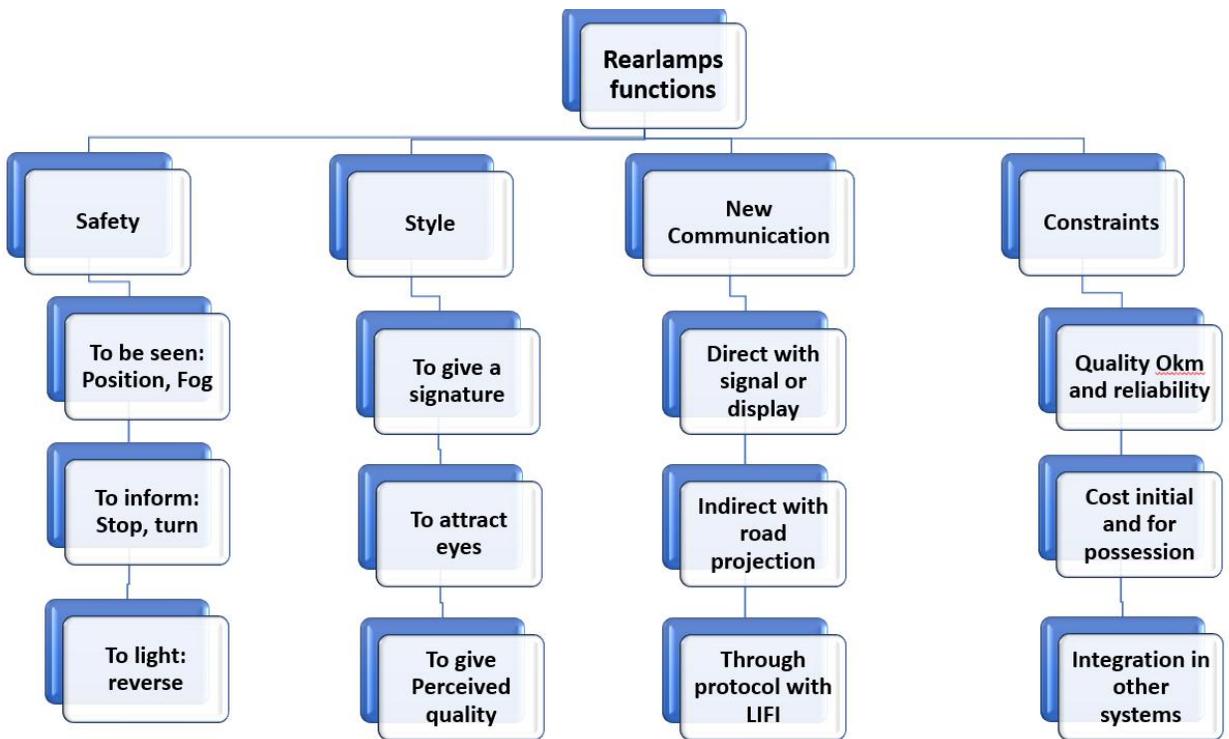


Chart of traditional functions of rear lamps

5 · Safety: regulation for rear lamps

5.1 Regulations

👉 This information is provided by DVN on an overview basis for educational and illustrative purposes. It is not meant to be relied on for compliance purposes. 👈

Primarily, rear lamps are focussed on functionality to advertise to other traffic participants the presence of the vehicle and the manoeuvring intentions of the driver. A clear signal is unique in terms of its colour, intensity and positioning on the vehicle. The signals should be intuitive, unambiguous, easy and quick to acquire correctly without taking any time for interpretation, difficult to misinterpret, and uniform across all vehicles.

As rear lamps became a vehicle design feature, and vehicle design diversified from a rectilinear box on wheels, the technical requirements became more difficult to define in terms of position from the edges of the vehicle, separation of the coloured functions, the maintenance of luminance ratios between the functions etc. Consequently, the UN Regulations included a definition of "apparent surface" and methods to determine the edges of each function to be used to position the lamp correctly in relation to the edges of the vehicle.

The American regulation contains requirements for "Effective Projected Luminous Lens Area (EPPLA)", more or less meaning the size of the lit area. EPPLA was devised in the 1960s as a means of limiting the maximum luminance of signal lamps to prevent glare at close viewing distances—at that time it was very difficult to directly measure luminance—and might have also served to guard against the entire lamp being covered by mud, snow, or slush. It served these needs reasonably well when all signal lamps used very similar technology: incandescent bulbs with parabolic reflectors or fresnel lenses, always with the outer lens as the surface of optical diffusion. EPPLA became largely detached from practical reality with the advent of window-clear outer lenses and complex-optic reflectors. LEDs and other new technology are so far from the original assumptions behind EPPLA that it now poses severe design restrictions and blocks good, effective signals while provoking lamps designed to meet the (undefined) EPPLA tests rather than being designed for optimal function. And since there is no prescribed or agreed way to measure EPPLA, it is not an objective requirement with repeatable measurements. Nevertheless, EPPLA remains one of the requirements in American rear lamp regulations, and so it continues to exert leverage.

The design pressure to produce a new image for the vehicle as part of its marketing appeal results in many questions about whether a particular arrangement will meet the existing regulatory requirements, or whether amendments to the regulations are necessary.

The outcome of these numerous requirements for the rear lamps sometimes results in long discussions with the regulators, to decide what innovations are acceptable and how they will be specified, or to identify what innovations are not acceptable. The prime focus of the regulators is at least nominally that of safety for all road users (though industrial, commercial, and political factors have a way of working themselves into the mix) so any proposal to amend the regulations must, at least in theory, be backed by clear evidence of the safety implications. Ideally there should be a clear safety benefit to any new kind of signal light, but the regulators also have a responsibility to ensure that regulations do not become an unreasonable barrier to trade, or a thumb on the scale in favour of one company or country over another.

Rear lamps are an important part of the design of the vehicle that must appeal to the end users for the car to be competitive and successful in the market. This means regulators are sometimes requested to allow the installation of lamps that may not offer a safety benefit; in this case the emphasis falls on the innovators to demonstrate that there are no safety **dis**benefits.

5.2 Status of innovations currently under consideration by regulators

Welcome lighting when approaching a parked vehicle and remotely unlocking the doors (animated displays around the vehicle using colours other than white, red, and amber and welcome messages projected on the road surface when car doors are opened)

Currently these functions are being installed on vehicles, and only operate when the vehicle is stationary based upon definitions of the "normal operating condition" and "park condition" of a vehicle as defined in UN Regulation № 48 (Installation of lighting and light-signalling devices). These definitions can be found in paragraphs 2.3.10, 2.3.11 and 5.1.

However, some regulators have qualms about the possible disturbance to traffic that may be caused by some parked vehicles installed with welcoming sequences that are increasingly active and multicoloured. Manufacturers are encouraged to fully discuss their specific applications with the regulatory authority in the countries where they intend to market the vehicle.

Light bands at the rear of the vehicle

The current provisions of UN Regulation № 48 allow the installation of light bands on the front and rear of the vehicle. The relevant paragraphs are:

- 2.4.11.2 (Supplement 12 to the 06 series of amendments to UN Regulation № 48)
- 5.7.2.3 (Supplement 12 to the 06 series of amendments to UN Regulation № 48)
- 5.7.2.4 (Supplement 5 to the 06 Series of amendments of Regulation № 48)

Other relevant parts of 06 series of amendments to UN Regulation № 48 are:

- 6.7.4.1 Stop lamp (Regulation № 148)
- 6.9.4.1 Front position lamp (Regulation № 148)
- 6.10.4.1 Rear position lamp (Regulation №148)

Illuminated logos

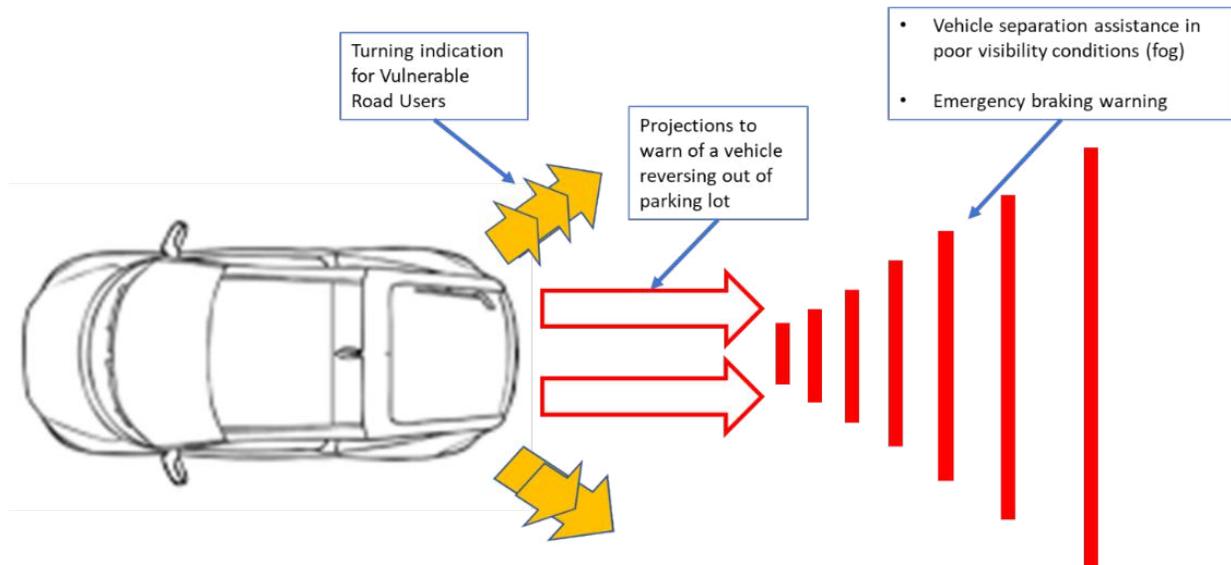
Over the years there have been discussions relating to the installation of illuminated logos on vehicles and, generally, governments have avoided taking a decision to allow them in the regulations. However, as light source technology has evolved there is growing pressure from manufacturers. This has intensified as examples of illuminated logos are being installed as original equipment on vehicles in China. Although illuminated logos are not included in the Chinese GB standards they are being allowed, although it is not clear upon which basis they are approved. It is likely that they are being certified as part of another lighting function.

As the Chinese TC114-SC21 Committee has started to discuss provisions to be added to the GB standards it is likely that, if GRE adopts the French-German proposal, the GB standards will follow the adopted UN text.

Regarding the UN technical requirements, GRE is currently considering a French-German proposal to allow them to be incorporated as part of the front or rear position lamp. Only the vehicle manufacturer's logo will be permitted; other symbols will not.

Unlike the UN Regulations, which are based on the philosophy that whatever isn't specifically allowed is considered prohibited, the American regulations operate on the opposite principle: whatever isn't specifically prohibited is considered allowed—as long as it does not impair the effectiveness of any required equipment or feature of the vehicle. The configuration and commercialisation of illuminated logos for the American market, therefore, must be done with due care not to impinge on the visibility, conspicuity, or clarity of any required lighting functions.

High resolution projections on the road surface



Turning indication for Vulnerable Road Users using projections on the road surface

This feature is currently being studied by GTB and offers potential advantages. However research will be required to demonstrate that the signal will be effective in traffic without causing confusion to other traffic participants.

Projections to warn of a reversing vehicle

GTB has funded research on the projections to warn of a vehicle reversing out of parking lot. This research, presented by Dr S. Azouigui at ISAL 2019 demonstrated very positive results, and GTB is now considering how this can be introduced into the regulations. (Impact of Advanced Lighting Function based on Road Projection for Departing Indication in Parking Lots 375 S. Azouigui, B. Barbedette, S. Saudrais, Y. Sortais, 1ELS – ESTACA / Institut d'Optique Graduate School, France, S. Bordel, Cerema, France, C. Neumann, P. Jahn, KIT – Light Technology Institute, Germany)

Vehicle separation assistance in poor visibility conditions (fog)

Emergency braking warning

So far, no studies have been initiated by GTB. The concern is whether these functions could be a distraction or impediment to nearby drivers.

AV LIGHT SIGNALLING FUNCTIONS

(INCLUDING DIGITAL OLED SIGNS MOUNTED ON FRONT AND REAR)

At the 80th session of GRE (23-26 October 2018), GTB presented its position paper [GRE-80-16e-Rev.1](#) and, in response, GRE decided to launch the ASVR task force (Autonomous Vehicle Signalling Requirements). The scope of the task force is to *evaluate and report on the safety needs for automated and autonomous vehicles to signal their status and communicate their next intended actions using visual or audible signals or a combination of both.*

In April 2019, GRE was briefed on the progress of the ASVR task force, which had not been able to reply to the main question on whether or not there should be a safety requirement for automated/autonomous vehicles to provide specific signals. GRE was not able to reach a consensus on this question either; some experts felt that such signals were necessary for safety reasons, some others held a different view. The expert of SAE advised that the SAE Lighting Systems Group is drafting an SAE standard for automated/autonomous vehicles.

GRE is awaiting guidance from WP.29 including a conclusion on the possibility of developing a new UN Global Technical Regulation (UN GTR). Logically, this will be necessary to ensure that there is a common prescription for the light-signalling functions of automated/autonomous vehicles.

In the meantime, the following groups are involved to try to reach a conclusion on the way forward, including

- GTB Signal-Lighting Working Group
- GRE AVSR Taskforce (Autonomous Vehicle Signalling Requirements)
- WP.29 (World Forum for Harmonisation of Vehicle Regulations)
- WP.1 (UNECE Global Forum for Road Traffic Safety). This is the highest authority in UNECE- Geneva and joint sessions of WP.29 and WP.1 the World Forum with the Working Party on Road Safety (WP.1) are being held.

5.3 Activities to remove regulatory barriers to innovation

The American regulation differs substantially to the UN Regulations observed, to one degree or another, virtually everywhere else in the world. The US regulation has various points of superiority and inferiority relative to the UN Regulations in the particulars of its requirements, but overall the UN Regulations and their coöperative development process are innovation-friendly, while American regulators are extremely reluctant to update or adjust their regulations, even where would be a clear safety benefit.

China is not a signatory to the UN 1958 agreement and operates its own GB mandatory standards system and manufacturers are often unable to market the latest European technologies in the Chinese market. Here the problem is one of synchronising the Chinese GB Standards with the amendment of the technical requirements in the UN regulations. In principle the Chinese policy is to follow the UN technical requirements but there is a time lag of at least five years between the publication of the revised GB standards.

It is clear that many regulators consider that the vehicle light-signalling regulations are mature and their constant update is an administrative burden. We see that the resources and priorities of governments are focussed on the emerging issues associated with the environment, automatic and autonomous vehicles.

The consistent message from the various conferences held regularly around the world, is that there is great interest in automotive lighting and signalling both in terms of increasing traffic safety and in augmenting the customer appeal of new vehicles. Lighting remains, by definition, a highly visible feature and therefore an important element of vehicle design.

The rapid development of light-source technologies, that are now delivering high efficiency LED devices, is leading the innovation of solutions and functions that until a few years ago could not be realised. This relates to photometric performance and also, importantly, to energy efficiency to reduce the demands on the vehicle's power supply. Now the vehicle manufacturers also have the opportunity to use lighting to enhance the appearance of the vehicle and the comfort of the driver.

It is clear that **good lighting sells cars!**

This newfound freedom to add features and functions to a vehicle to increase customer appeal, in addition to sometimes enhancing safety, is not without baggage of its own, for a vehicle operating in traffic is required to do so safely for all users of our increasingly-congested roads. In all countries traffic safety is a high priority and, over the past 70 years, much progress has been made to reduce accidents and fatalities, despite the continuous increase in traffic. The United Nations Working Parties, WP.1 (UNECE Global Forum for Road Traffic Safety) and WP.29 (World Forum for Harmonisation of Vehicle Regulations) continue to spread their influence. The WP.29 subsidiary expert working group (GRE) actively develops and updates UN Regulations in coöperation with governments, industry and non-governmental organisations. These regulations ensure continuous safety improvement whilst also ensuring that industry can innovate for truly clear commercial benefits to the global economy.

While the opportunities to innovate, and the fact that good lighting sells cars, are important they also bring difficulties because the essential regulatory framework to allow the innovations to be exploited is not always supportive. Manufacturers increasingly complain that the regulations are proving to be a barrier to innovation and demand that action is taken. However this is not a new phenomenon; it is usual for regulation to follow innovation but, in this active field of automotive lighting, a new initiative is required. GTB is being asked to use

its unique organisation to bring the 'global lighting family' together to cooperate with the regulators, but this is against a background of significant difficulties that have to be overcome.

In January 2020, DVN and GTB carried out a confidential survey of opinions of their members to help understand the issues associated with the regulatory barriers to innovation. The detailed responses and the summary of the actions required were reported in detail in the 2020 DVN Study "New Lighting Functions 2020-2030". The main recommendation resulting from this DVN/GTB survey was that focussed lighting groups should be created in Asia, Europe, and North America to develop an understanding of the issues and a common proposal for a way forward to produce harmonised technical requirements that can be adopted into the national legislation using a procedure to maintain alignment with the evolution of the work in GRE.

The outcome of the DVN/GTB survey also concluded that non-governmental organisations (NGOs) representing automakers and suppliers should combine their resources to develop recommendations and plans for adaptation of the regulations and to jointly approach the regulators. However, the reality is that NGOs are required to operate democratic procedures to reach a consensus before they can formally submit proposals at WP.29 and GRE. This is already difficult for one NGO, such as GTB, but for a group of NGOs to achieve a joint consensus is a very steep challenge.

There have been 16 regulatory sessions during DVN Workshops held from 2012 to 2020 with the objective of building a consensus to develop worldwide harmonised technical requirements. At the 2018 DVN Workshop in Tokyo there was a clear agreement among representatives of regulators, vehicle manufacturers, and suppliers, that supported the objective of building a consensus. But the reality is that **EVERYBODY** is waiting for **SOMEBODY** to make the first move, so **NOBODY** has yet!

Geoff Draper, recently retired from his position as GTB President, is now operating as an independent regulatory advisor and has offered his time in retirement to establish and lead national interest groups using the DVN platform. He plans to communicate using established platforms including DVN, LinkedIn, and WeChat supported by occasional videoconferencing.

5.4 Outlook

It is clear that the freedom to innovate in rear lamps presents significant challenges because of the difficulty to gain regulatory acceptance of innovations. Where there is a proven safety benefit the regulations can be quickly updated (except in America) but many innovations are primarily to provide new marketing opportunities and, at best, they are safety-neutral. Regulators are tasked with seeking to avoid regulatory barriers to trade; moreover, they need independent research data to confirm that innovations for design and marketing reasons do not compromise traffic safety through distraction or confusion of drivers and vulnerable road users or by any other dint.

To have the best chance of amending the regulations to allow innovations, industry must proactively work with the regulators and with GTB by providing clear justifications supported by real-world demonstrations and good quality data from rigorous independent research. Industry must also accept that not all innovations will be accepted by the regulators, and this should be considered in the early stages of a new vehicle programme.

6 · Style: Demands and Trends

Rear lighting is now an especially important aspect of the global style of a car, generally giving the signature of the brand. LEDs are now the standard technology, granting broad freedom to designers.

As seen in recent motor shows, the strong current trends are very thin rear lamps, often spanning the full width of the rear of the car, presenting logos when authorised; equipped with precise internal decoration and lighted elements, with a temptation to appear like a display, and signing the brand as much as possible.

6.1 Thin rear lamps

Naturally, this trend to have slim rear lamps is only possible with LEDs. The trend is to have elegant rear lamps with a reduced height, but still clearly visible: there is no temptation to hide them behind the body of the car as seen formerly.



Genesis G80 electrified



Evergrande Hengchi 1



Honda HR-V



Genesis X Concept

6.2 Spanning the full width of the car

A majority of today's new cars have edge-to-edge rear lamps. Despite their cost, designers like this way of giving a higher-status appearance and helping to deliver the signature. The lamps on the quarter panels generally fulfil the legal requirements for the main functions (tail, stop, turn signal; required to be mounted on a fixed part of the vehicle body unless a separate set of fixed-mounted lamps is provided for when the movable body part is out of its closed position—as can be seen on some Audi Q models). The lamp or lamps on the deck lid or hatchgate are essentially an extension of the rear position lamp.



VW ID.6



Lincoln Zephyr



Mercedes EQB (above) Audi Q4 (below)



6.3 Illuminated logos

Illuminated logos are now only permitted in a few countries, like China. They are strongly helping to advertise brands during nighttime—particularly interesting in China where so many brands are present.



← Audi A6 e-tron

6.4 Precise internal decoration

The external shape is not the lone interest of designers: the interior is also designed with often many well realised details, trying to structure the light to achieve a decorative, sculpted object of art.



Hongqi L-Concept



Evergrand Hengchi 2



Lexus ES



VW Polo



Mercedes EQS

6.5 Appearing like a display

Displays are still not permitted, but some realizations are priming for their arrival with many lighted elements that could be organised to deliver messages.



Lexus LF-Z Concept (above)



Audi A6 e-tron



Zhiji L7



Hyundai Ioniq concept with pixelated rear lamps

6.6 Signing the brand

The recognition of the brand through rear lamp design—day and night, lit and unlit—is particularly important for design and marketing. These signatures could be significant symbols as with Peugeot and MG, or could be a specific shape to the brand used often both for the front and the rear as for instance the triangle for SEAT or the T of Hyundai.



MINI Cooper with symbol of UK flag



Peugeot 308 with the 3 symbols of lion's claws



Seat Ibiza with brand-specific triangle shape



T signature of the Hyundai Santa Cruz



X signature of the Citroën C5 X



Brand-ID thin upright lamps for Cadillac Lyriq



BMW VBX6 with Ventablack structural wave rear lamp

For some car makers, the signature is not necessarily the same for all models, but there is a kind of family look to the different rear lamps of the range, with also some evolution permitted by the evolution of the technology. Hereafter the example of cars from VW.



Passat 2014



Tiguan 2016



Golf 2017



Touareg 2018

7 · Technologies for traditional functions

7.1 Incandescent bulbs

Bulbs were used since the beginning of electric rear lamps in the 1910s. Bayonet-base and wedge-base bulbs described in section 3 of this report are still widely used today, though they are increasingly being pushed aside in new-car designs by LEDs systems, at least in developed countries.

The UN Regulations, specifically № 37, categorises bulbs with meaningful designations. Bulb types that start with P have a prefocused metal bayonet or plastic wedge base; those starting with W have a glass wedge base. A second letter indicates bulb colour: Y for yellow (amber), R for red. The first number indicates the nominal power rating for the bulb's major function (or its only function, if there is only one filament). So a W21W has a nominal power rating of 21 watts. The second number, if present, indicates the power for the bulb's minor function. So a P27/7W bulb has a 27w major filament and a 7w minor.

Example of data sheet for W21/5W:

- Power at 13.5v: 25 / 6W
- Nominal voltage: 12V
- Luminous flux: 440 /35lm
- Tolerance for the flux: $\pm 15\%$ / $\pm 20\%$
- Lifetime B₃: 250/600h
- Lifetime T_c: 500/1600h
- Diameter: 20mm
- Weight: 6.8g



Generally due to regulation and cost, one bulb is used for each function, limiting the possibilities for style, though it is possible to have another tail lamp on the trunk to achieve larger rear lamps.

Another limit for style is the level of flux: enough to achieve the functions with standard reflector optical systems, it was sometimes complex to achieve some design needing several internal screens, for instance with the subtractive camouflage-colour design lamps described earlier in this report. However, there is a flip side here: a given incandescent bulb offers its full measure of luminous flux at one inexpensive price. Especially with advanced optics, this means often more flux is available than is required for minimal compliance, so a higher-performing lamp can be produced at no extra cost. This is not the case with LEDs, where each and every lumen must be bought at a cost, so there is some disincentive to provide higher-than-required performance.

Incandescent bulbs produce much more heat than light, which requires a minimum size for the reflector and a minimum distance between the bulb and the plastic parts of the rear lamp. Occasionally, a metal sheet protective barrier above the bulb is used to avoid plastic melting, or/and more thermally resistant housings, such as polycarbonate rather than lower-melt ABS.

Light guides were naturally impossible with plastic: only glass should be possible but was not really used due to its complexity for that application (conversely, glass for used at the front for some realizations, for instance BMW round light guide "Angel Eyes" DRLs)

Another characteristic of bulb is their relatively slow rise time of about 250 milliseconds to deliver the nominal flux—a delay that could be considered small, but hampers the stop light function by delaying its perception by following drivers. The instant-on characteristic of LEDs gives a following driver 6 metres' extra stopping

distance at 80km/h. However, a [2013 NHTSA analysis](#) was unable to find any crash-reduction benefit to LED stop lamps.

Examples of traditional rear lamps with bulbs:



Audi RS6 2004: red appearance for turn indicator (pink outer lens, green inner lens)



Renault Laguna 1994: grey look for turn and reverse



Peugeot 106 full red appearance 1996 with inner green filter and light collimator



Recent bulb rear lamp: Fiat Mobi Trekking 2021 Brazil with crystal appearance for reverse and turn for turn

Bulbs are generally mounted with a metal frame circuit attached to a plastic frame, often but not always with a sealing gasket.



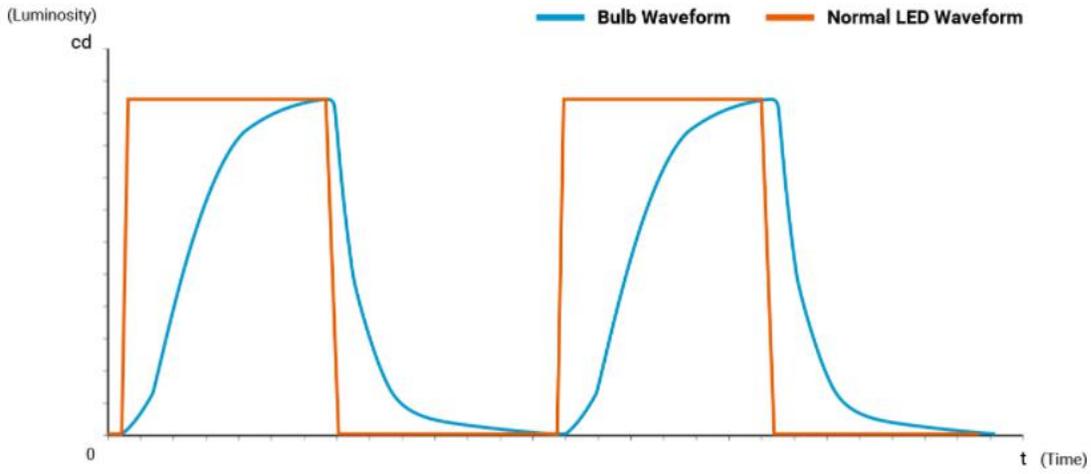
7.2 LEDs

7.2.1 Appeal of LEDs

LEDs are becoming the standard source for rear lamps, thanks to their important advantages compared to bulbs:

- Much better style flexibility: numerous sources, possibility of light guide, surface guide, possibility to define original internal structures, etc.
- Compactness: possibility to significantly reduce the depth from around 100 mm to 20 mm
- Reduction of thermal constraints for materials
- Reduction of power consumption: a normal function as the stop or the turn function uses 25 watts, while an LED system can achieve similar photometry with less than 5 watts. The real consumption of LEDs depends on the required style; to achieve good homogeneity with light guides, the efficiency could decrease to less than 10 per cent.
- Better purity of red and amber colours, giving a more modern and attractive appearance

- Immediate illumination avoiding delay for the information to other road users

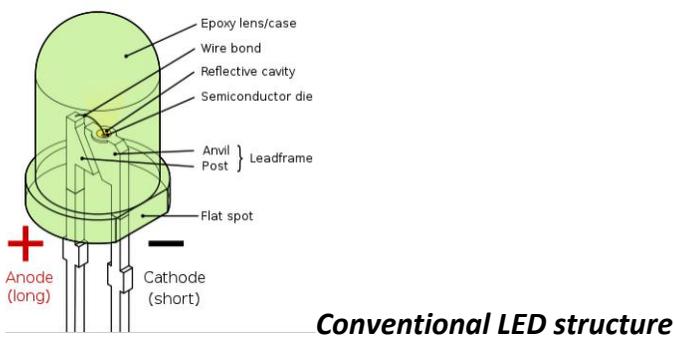


Compared to bulbs, on the technology side, there are only advantages for LEDs. The lone drawback that explained the relatively slow introduction was the cost, greatly reduced since the beginning, but still significant—this is why LEDs are still not present in the most affordable cars particularly in developing countries.

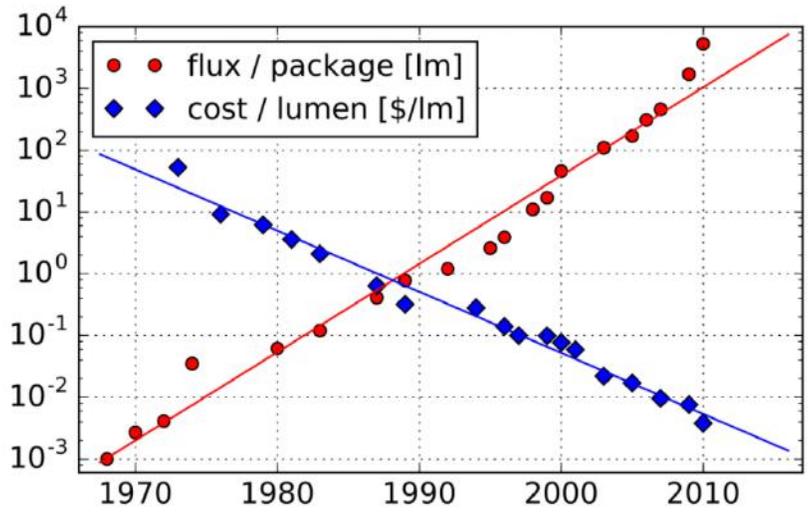
7.2.2 LEDs for rear lamps



LEDs appeared first in CHMSLs, the first one being the 1986 Chevrolet Corvette, and spread to other rear lighting functions in 1993. These first applications used conventional red LEDs.

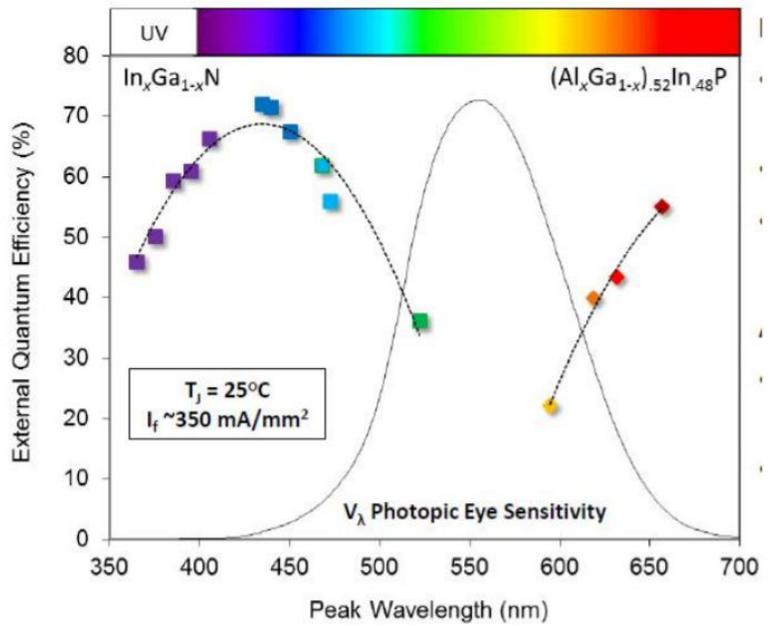


At the beginning for automotive applications, these LEDs had an extremely limited flux, only a few lumens. The improvements for flux and cost were however very quick, illustrated by the Haitz's law graph shown here.



Evolution of flux and cost of LEDs: Haitz's law

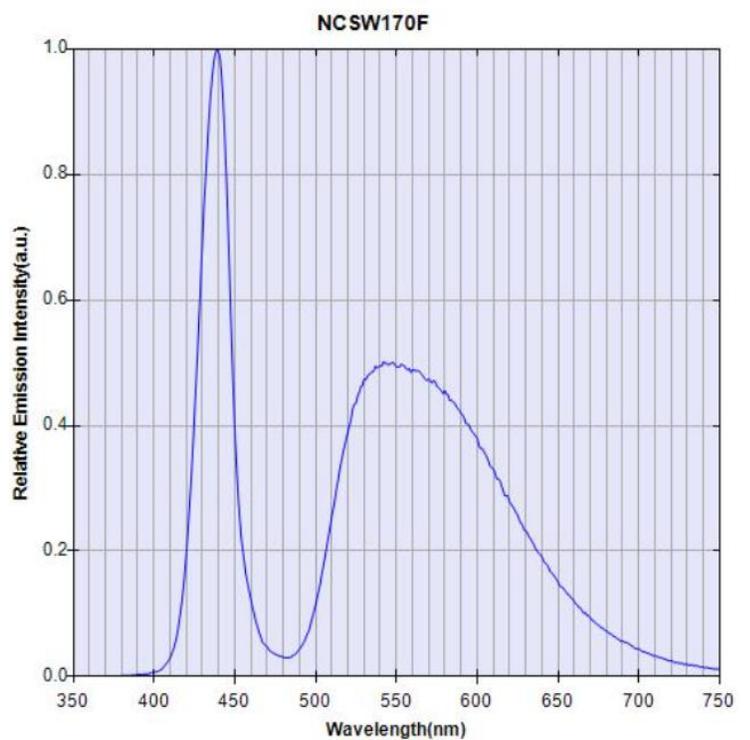
LEDs are diodes emitting a monochromatic flux depending on the base materials composition. Two main compounds are used: InGaN (Indium-Gallium-Nitride) and AlGaInP (Aluminium-Gallium- Indium-Phosphore), the first one emitting violet-blue-green light, and the second one yellow-amber-red light.



Typical efficiency of LED Lumileds)

For rear lamps, monochromatic AlGaInP LEDs were used to produce red light for stop and tail functions and later yellow light for turn indicators.

Reverse lamps needed to wait the invention of white LED in 1996 by Nichia. White LEDs use blue LEDs with a layer of phosphor converting part of the light to yellow; the admixture is seen as white. Shown here is the spectrum of a recent white LED, displaying a first peak of blue and a second more extended wavelength area in the domain from yellow to red due to the phosphor conversion.

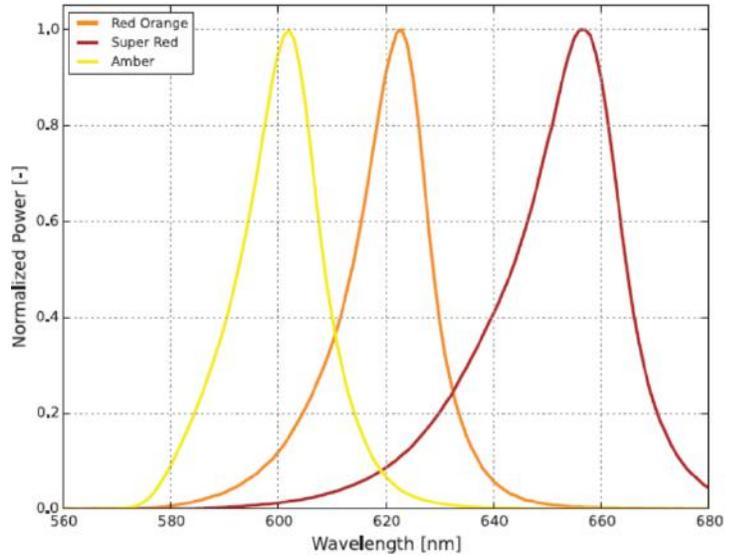


Spectrum of Nichia NC SW170F

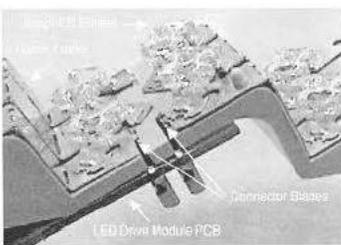
InGaN LEDs have a significantly better quantum efficiency than AlGaInP, with a better thermal resistance authorising much higher flux. So, these LEDs are not only used for white functions like the reversing lamp, but

also more and more for the yellow turn indicator or the red stop-tail-fog functions with specific layer conversions.

For signalling, one of the most important characteristics is the spectrum: typically, yellow (amber) for turn signals is centred at 600nm, regular red ("red-orange") at 625nm, and super red at more than 655nm. Red-orange and super red can be used for stop-tail-fog, but super red gives greater differentiation from the incandescent-bulb appearance.



As regards the mechanical structure of LEDs for signalling: following the initial conventional LEDs, many kinds have been used. To allow 3D positioning, Lumileds proposed during the first decade of 2000 "SnapLED" on metal circuits that had a large diffusion.



Lumileds SnapLED on clinch frame

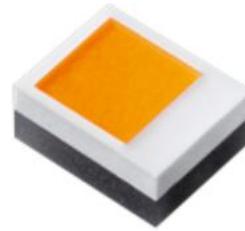
Now, the trend is the use of SMD (Surface-Mounted Devices), that can be directly welded on electronic circuits, including flexible circuits.



Examples of LEDs from Osram, Lumileds, Nichia, and Seoul SC

Sample data from the Nichia NCSA170F, a recent red orange LED:

- Emitting surface size: 1.15 × 1.15 mm
- Chromaticity coordinates: X: 0.57 Y: 0.42
- Luminous Flux: 280 lm
- Forward voltage: 3.5V
- Thermal resistance: 3.3 °C/W
- Maximum intensity: 1,500 mA
- Maximum junction temperature: 150 °C



Even disregarding the mountain of illegitimate "LED bulbs", even bona fide suppliers are now providing LED retrofits for incandescent bulbs. Some of these bring some of the benefits of LEDs to older cars: lower power consumption, less heat dissipation, purer colour, instant-on, indefinite lifespan. Difficulties are that these bulbs are optically compatible and work acceptably in only *some* lamps they physically fit in—not all of them—



and most consumers do not know or care the difference. There are also issues of electrical incompatibility with turn signal flashers (improper flash rate) and bulb outage detectors (false detection). But in some cases, they really work well—as seen in [this video](#) (note especially the slow-motion demonstration at 3:25).

←Osram LEDriving (Sylvania Zevo) P21/5W (1157) Red retrofit bulbs

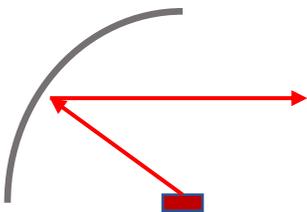
For more details about the principles and characteristics of LEDs, have a look at the **DVN report "Evolution of Automotive LEDs 2015-2025 – Outlook of innovation opportunities"** published on September 29th, 202

7.2.3 Optical technologies for LED rear lamps

Some principles—parabolic reflectors, complex reflectors, and fresnel lenses—used for bulbs can also be used with LEDs, naturally with generally much more compact units. But some optical systems cannot be considered with bulbs, for instance light guides used with many LED rear lamps.

Reflector technology

One of the simplest, least-costly technologies. As LEDs emit hemispherically (compared to bulbs emitting spherically) reflectors can be put above or below the LED source, or at the back of a parabola. Even if the intensity requirements can be met with one single LED, generally several LEDs are used to achieve the style targets. The cost can be minimised with a flat electronic board including both the LEDs and the electronic control for intensity. The efficiency can reach a good level of around 50 per cent.



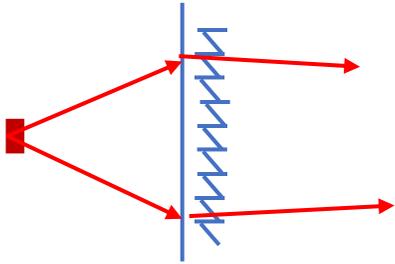
Reflector principle

Dotty appearance with snapLEDs

Audi A1 rear lamp with reflectors

Fresnel technology

Prisms and striations in an inner or outer lens can shape the light directly from the light source to achieve the targeted pattern. In this case, the efficiency is good reaching 50 per cent, but the aspect ratio is poor. Often the fresnel lens is used as a primary optic to illuminate another lens generally with a translucent diffusing material achieving a very good homogeneity at the price of efficiency that can be reduced to less than 20 per cent.



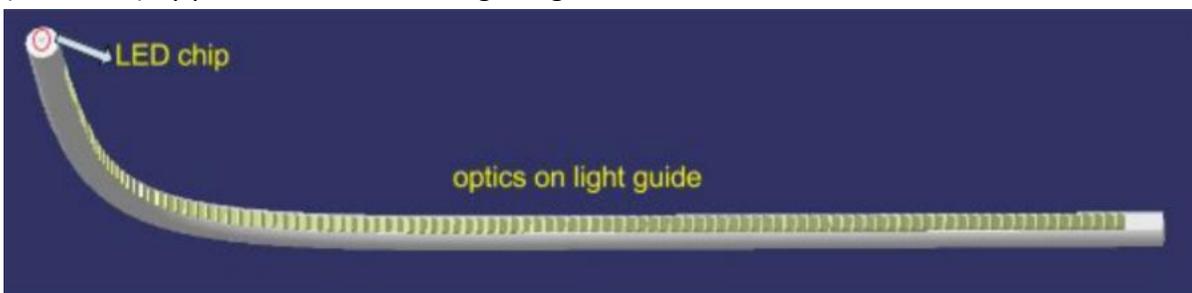
Fresnel principle



BMW X3

Linear light guide technology

The light guide technology is certainly the most used with LEDs for rear signalling. The principle is simple: a LED is placed at the extremity of the light guide and the light is confined within the guide by total internal reflection until it is "outcoupled" (extracted) by prisms or texture along the guide.



Turn indicator with LED light guide

Light guides have many benefits: huge flexibility of style with straight lines, bends, curves, angles, shapes, etc; good homogeneity of the function, though complex calculations and precise realization are necessary for such an achievement; relatively free positioning of the source helping to save space, and ability to have more than one light colour from the same emitting surface (e.g., white position/DRL and yellow turn signal).

The homogeneity of light guide has a price for efficiency always relatively low at around 15 per cent. But the improvement for cost and performances of LEDs have helped to rationalise this solution.



Geely Xingyue



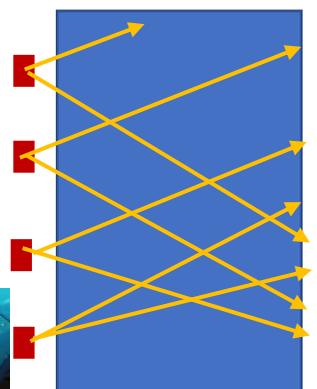
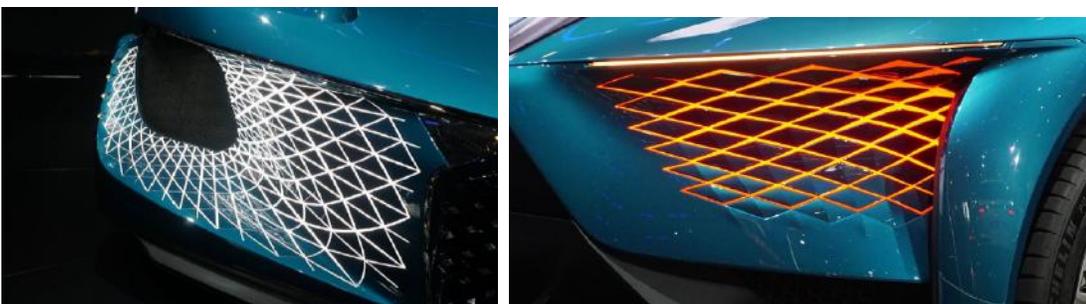
Renault Arkana

Light guide technology is helping to support the current trends to have exceptionally large rear lamps from one side to the other, and to have thin illuminated areas.

Curtain light guide or surface light guide

With this technology, several LEDs are placed on the side of a surface and the light is following the surface in different directions.

This technology has extremely low efficiency, sometimes around 10 per cent. It is mainly used for low-intensity functions like position lights and for decorative lights more and more seen in new models.





Hongqi L-Concept



Cadillac Lyriq

OLEDs can also give this aspect of homogeneous surface, even better than surface light guides.



OLED Audi Q5

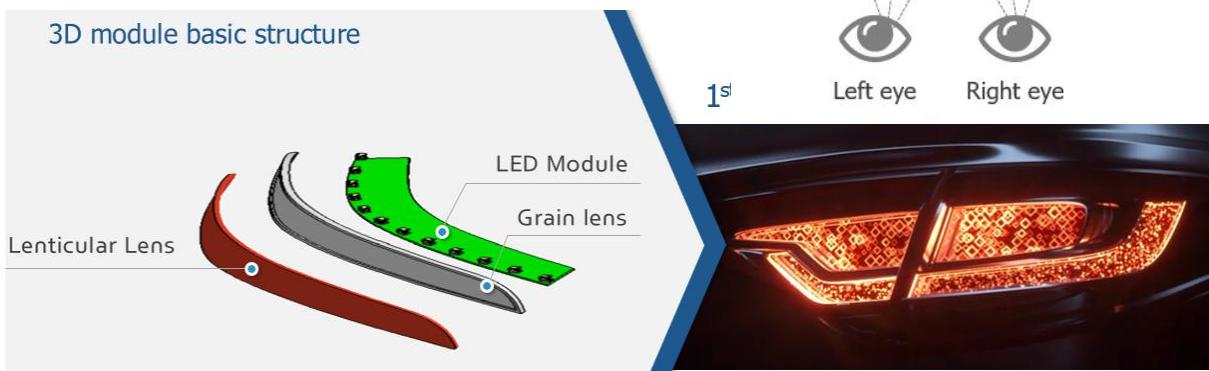
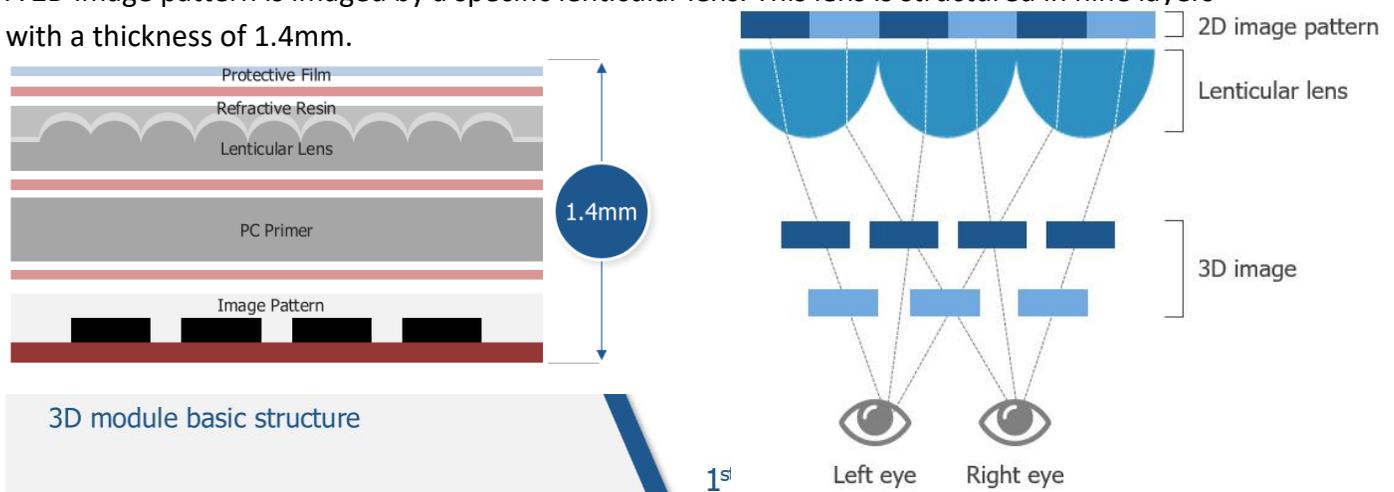
3D Appearance

Rear lamp technologies have evolved quite a lot in recent years with many styling proposals. One of them was the 3D appearance seen frequently on Citroën cars. This 3D appearance is obtained with at least two internal surfaces partly reflecting the light. The efficiency is relatively low and consequently the cost more expensive (remember, with LEDs every single lumen comes at a price!) than with a more direct lighting illumination.



Citroën C4 Picasso 3D

Mobis presented recently at a DVN Workshop another way of getting 3D images using a lenticular technology. A 2D image pattern is imaged by a specific lenticular lens. This lens is structured in nine layers with a thickness of 1.4mm.



7.3 OLEDs

Organic Light-Emitting Diodes use an emissive electroluminescent layer—a film of organic (carbon-based) compound that emits light in response to an electric current. This organic layer is situated between two electrodes; typically, at least one of these electrodes is transparent. OLEDs have very different characteristics compared to LEDs.

This technology is now used often for smartphones and TVs, but is still unusual for automotive applications, except for some premium models from the likes of Audi and Mercedes. The main reason is the cost still much higher than LEDs. Conversely, OLEDs are interesting as they allow new possibilities for style, with easily addressable discrete areas on the homogeneously lit surface.



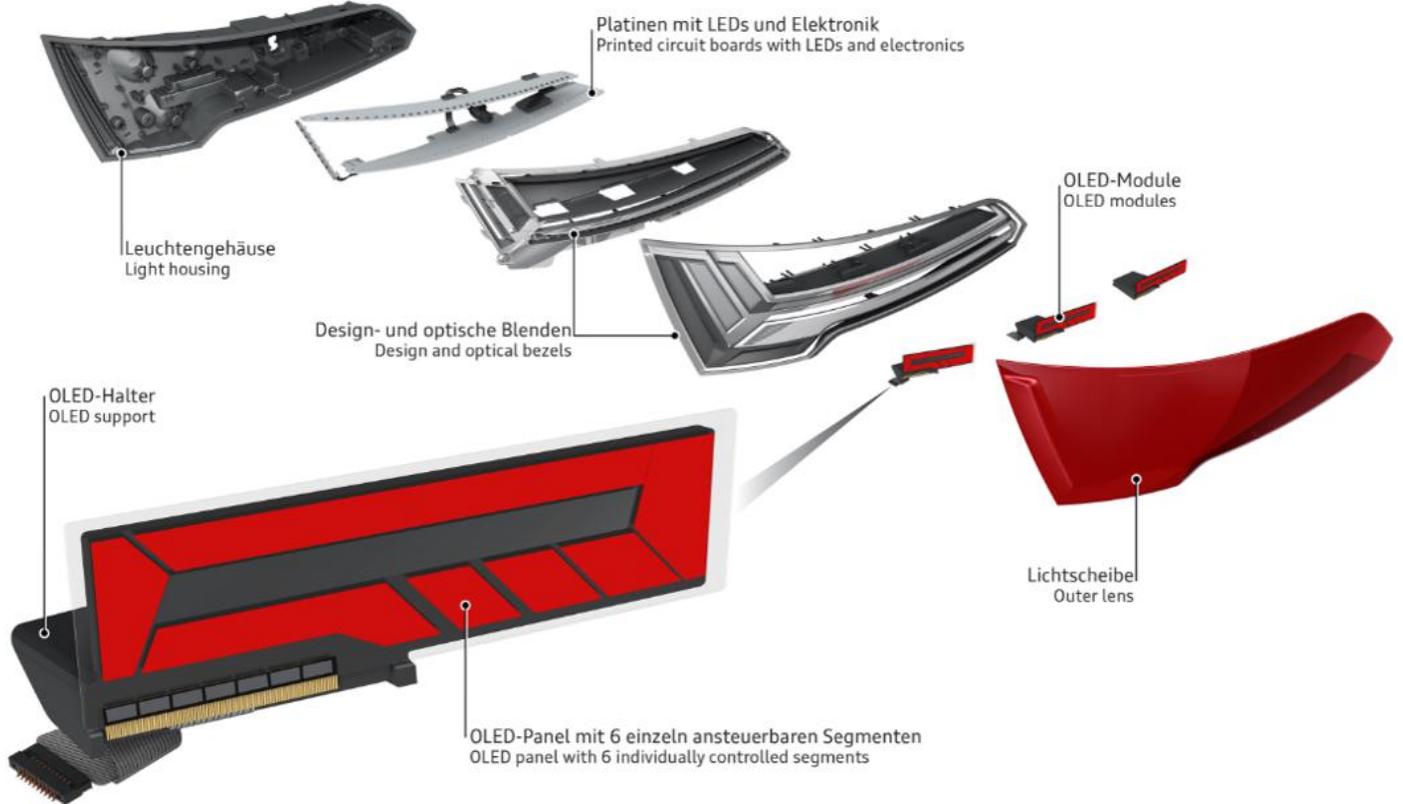


Flexibility of style with OLEDs

Curved lighting surfaces with OLEDs were out of reach for a very long time, but this barrier, too, is falling. For instance, some suppliers as OLEDWorks in Germany are preparing curve OLEDs in 2,5D with a minimum radius of 10cm. To allow that, glass would have a thickness of 0,1mm only and the total device 0,6mm with a brightness of 8,000cd/m2.



Audi Q5 detailed structure system with OLEDs



7.4 Animations with rear lamps: Sequential turn, ARS, welcome scenario

7.4.1 Wiping turn Indicator:

Recent rear lamps bear different animations, particularly for turn indicators with a wiping effect enhancing the directionality of the direction indication. The safety claim is based on the apparent movement being more noticeable for other road users. Recent UMTRI research suggests this is true and correct.

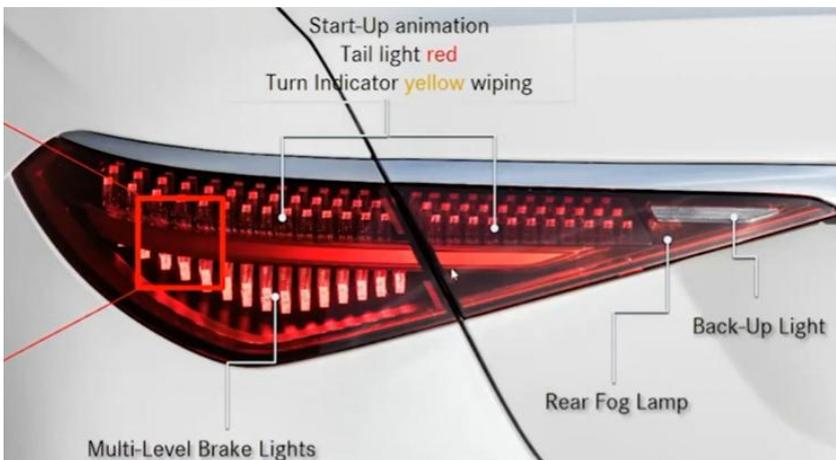
Several LEDs independently controlled are necessary to achieve the progression of the light. Light guides are often used for this, but other optical systems can also be considered.



Audi A6 with wiping turn indicator

7.4.2 ARS

ARS (Adaptive Rear-lighting System) is a remarkably interesting system optimising the output of rear lighting functions in a wide variety of conditions. Sensors detect the level of light transmission at the rear, which could be reduced due to dust, rain, or fog, and accordingly adapt the intensity and/or the size of the lit area within limits defined by the ARS regulation (for ECE products).



7.4.3 Welcome / farewell animations

As welcome scenarios are presented when the car is stopped, there is no limit due to regulation.

Dedicated lamps for this purpose would be a big added cost, so generally the welcome scenario is done by existing lamps; stop, tail, and turn indicator functions can be brought to the dance.

In some premium cars as in the Audi Q5, there is a possibility to adapt the signature of the car: the driver can choose among several different light signatures, with the possibility of more being available for purchase as an OTA (over-the-air) upgrade.



Different lighting signatures of Audi Q5 with OLED elements

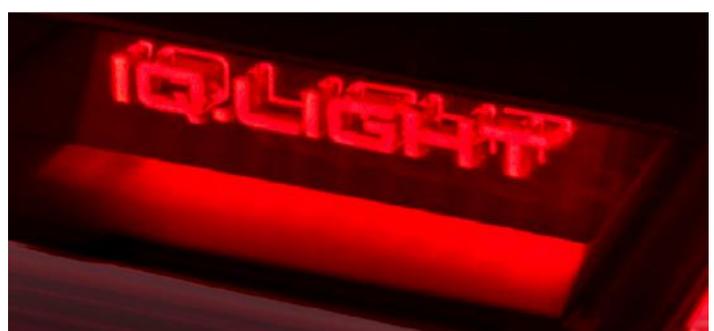


"Click-Clack" animation

Another kind of animation for rear lamps is the principle used particularly by VW that they are calling Click-Clack with not just a different intensity but also a different shape-size of the lit area for stop versus tail light functions.

7.4.4 Holographic light

Another interesting potential effect would be the use of holographic light. Holography is a well-known principle, but application to rear lamp is expensive. In the following mock-up presented by Volkswagen, the rear lamp would be totally transparent when unlit, and when illuminated a kind of magical signal in front of, above or behind the taillight can appear. With holograms, light can be generated where physically no space is available and so open the way to new designs.



7.5 Mechanical structure of Rear lamps

Rear lamps usually have a PMMA external lens as this material is scratch resistant, transparent, and relatively inexpensive. Other materials such as polycarbonate or Grilamid are also used.

The housing is generally made with ABS or ABS-PC, giving a good stiffness with a color that could be black or red depending on design.

Internally, at least for stylish rear lamps, several screens, lenses, and layers are used to distribute the light from LEDs and to achieve a very good homogeneity—one of the main criteria for rear lamp apparent quality.

Example of a modern LED Rear lamp with the BMW 5 series:

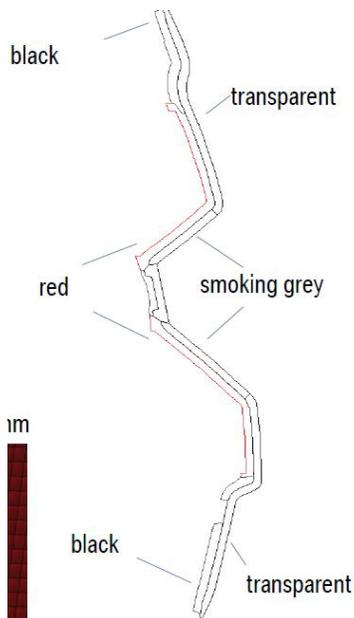
Tail/Stop Bi-Function



Tail and Stop function integrated in same signature.

Thanks to micro-optics in outer lens the functions get active as 3-dimensional illuminated body

Dark red appearance.



Turn indicator



Turn indicator with very small z-dimension.

Spread over both parts of the lamp.

High level of homogeneity.

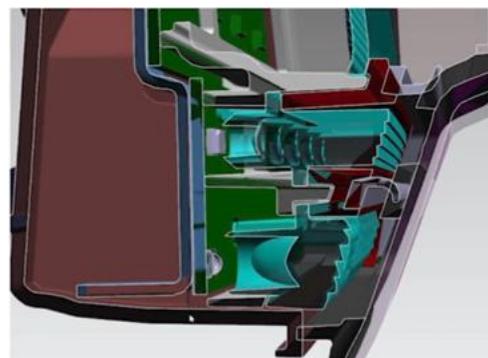
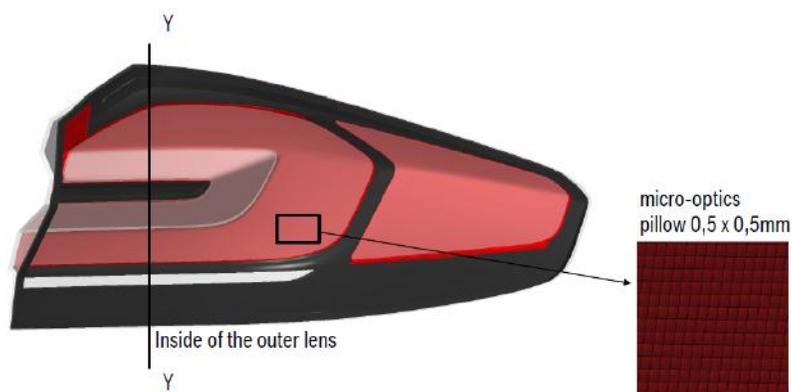
Reverse and Rear Fog

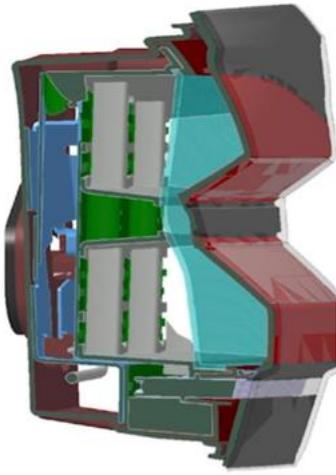


Functions tuned in order to achieve very compact space.

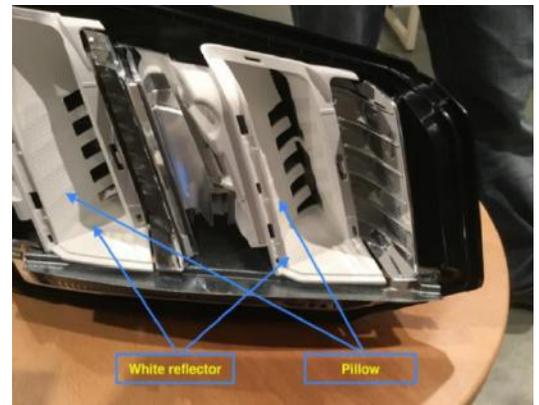
Reverse function provides well-spread illumination for rear-view camera.

To achieve a perfect homogeneity, microoptics with small pillows of 0.5×0.5 mm are used with different internal screens to improve the light distribution on the microoptics screen. Direct emitting LED are used on a circuit board. The external lens is often a multicolour injection part, Here for instance with four colours: black, red, smoked grey, and transparent:





To have a good efficiency, generally reflectors are metallised, but in some cases as in the Peugeot 5008, white plastic with no metallization is used to improve the diffusion and the final homogeneity.



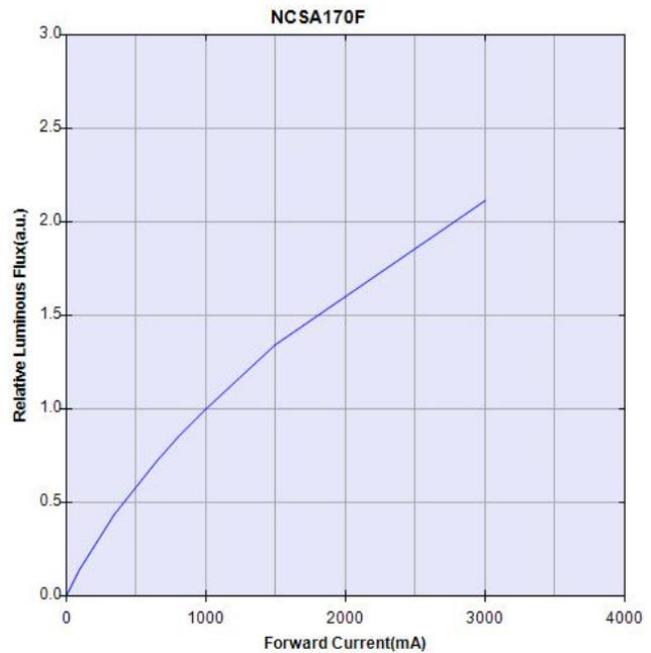
The assembly between the lens and the housing is generally done by welding the plastic materials with one of the following processes:

- Hot plate welding realised by heating the two parts and then joining them. This process generates reliable welds, but it's very difficult to have a good appearance of the welding line.
- Vibration welding is a simpler process wherein a high-frequency vibration between the two parts increases the temperature to the melting point. The welding line has a better appearance than with hot plate, but this process has two important limits: the geometry of the parts needs to be adapted to the vibration movement, and long-term reliability of the weld, particularly for water tightness, is difficult to achieve.
- Laser welding is a relatively recent innovation. The principle is to increase the temperature of the housing with a laser through the PMMA lens, with a robot or light guides. The appearance is much better, with less "dead" surface beyond the weld line, but it is a more expensive process.

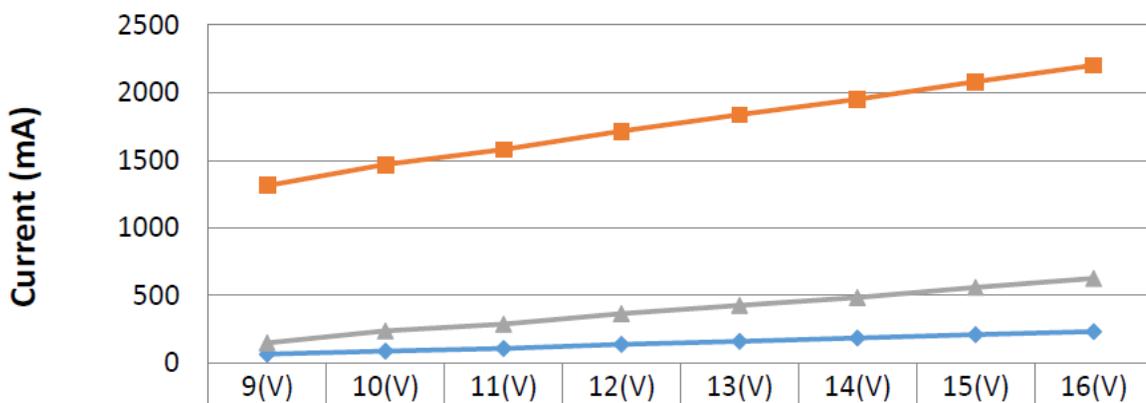
To complete the mechanical structure, a rear cover for access to bulbs and naturally integrating rubber for watertightness was used. Vents are also often used to avoid condensation inside rear lamps.

7.6 Electronic control systems

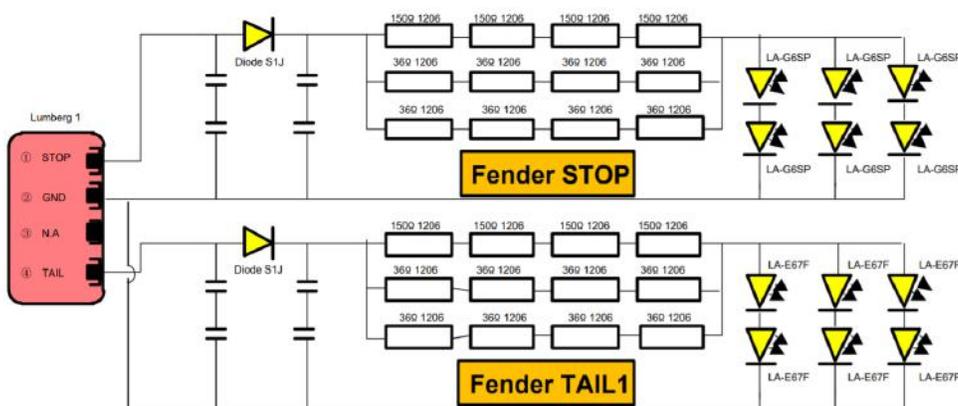
Bulbs were directly connected to the 12V supply. LEDs need a regulation to maintain the current as stable as possible. There is a first need to maintain the current constant as the flux varies with the current, roughly in a linear mode. Each LED has characteristics found in the data sheet that are used by electronic engineers to define their circuits. But they have also to consider the dispersion characteristics, as dispersion of positioning on the board could also cause variation of photometric values. A close development between optical engineers and electronic engineers is necessary to ensure proper results.



At the beginning of LEDs and still now for low-cost solutions, simple circuits with resistors are used helping to maintain the current of LEDs in acceptable limits. For instance, in the following example, current varies by 8.5 per cent from 12 to 14 volts and by 35 per cent from 9 to 16 volts, leading to flux variation.



Variation of current with resistor system (Orange: Turn, Grey: Stop, Blue: Tail)

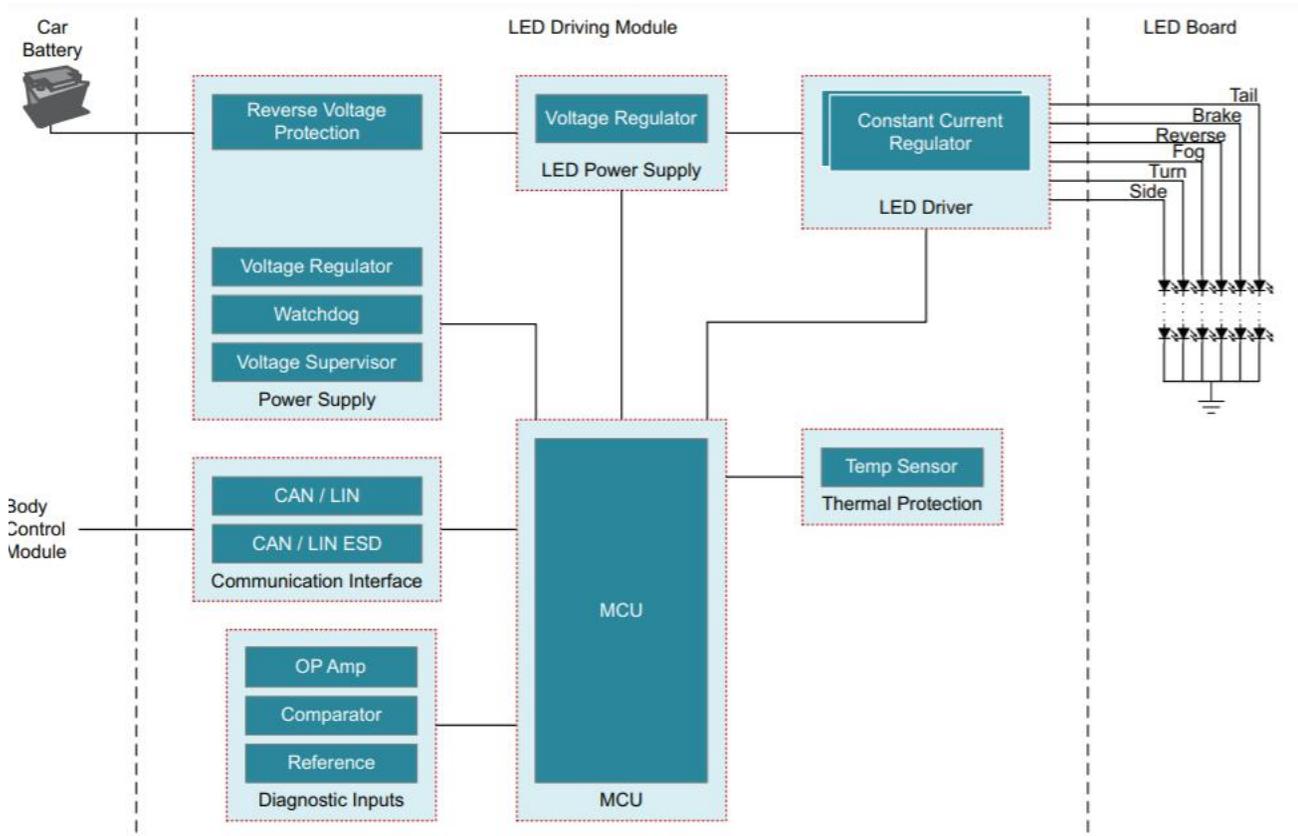


Example of resistor circuit of rear lamp, Peugeot 5008

These circuits are now more and more replaced by more complex integrated circuits including all the protections (voltage, thermal...) protections and the current regulation, but also specific controls for the new functions such as wiping turn indicators or welcome/farewell animations. Another important point is the communication interface with the body controller, generally using CAN or LIN protocol.

For modern premium cars, dual CAN buses are needed to handle the bandwidth of control signals.

Regulations require photometric measurements to be done after 30 minutes (for example) of runtime, to account for "droop" (tendency of LED output to drop as junction temperature increases with runtime).



Modern control blocks for rear lamp electronic control

Other important elements to consider for LED electronic circuits are:

- Electrical overstress: Maximum voltage and current need to be respected
- Reverse polarity: protection is needed
- ESD: Many guidelines are now used in plants to avoid ESD damages (ankle straps, wrist straps,...) and for the design (grounding the heatsink, good design of PCB...)
- Transient avoidance
- Noise: Radiated and immunity tests are systematically required for all automotive components.

8 · Technologies for new functions

Rear lamps are essentially a communication function for the other road users, the exception being the reverse function supposedly helping the driver by illuminating the rear, but even this function includes a message to others indicating that the car is reversing. In the near future, communication will likely be transformed by the improvement of the current functions by introduction of new technologies, which will also allow the creation of new functions. For instance, the current stop light or direction indicator could have their messages be better seen and understood by projection of symbols on the road, or by posting messages on displays inserted in rear lamps.

These two new devices can also deliver new kinds of messages, for instance with the road projection of wiping arrows to inform that the car is reversing, or with displays to indicate the nature of the risk detected by the car ahead.

8.1 Displays

Displays are not allowed currently, but several car makers and set makers are preparing their introduction.

Volkswagen, for instance, presented a prototype three years ago showing some new functions possible with displays:



Volkswagen prototype

In this example, the left image would inform following drivers about a danger ahead, and the right image would inform the driver approaching the car, its level of charge.

Naturally, as for every new function, regulation would have to be adapted and signs as much as possible be internationally standardised for a good understanding. The multiple-decade struggle for true harmonisation in traditional lighting functions bodes ill for this extra-crucial need.

Mind is also preparing prototypes in that direction as disclosed in a recent DVN Workshop.

In a first phase, only messages with roman characters will be possible as Chinese characters would need a much higher resolution.

Mini LEDs chips on silicon linear devices are used, the light emitting surface of the yellow/red/white elements having 1.5 mm width and a length from 16.3 to 74.5 mm. The prototype has a uniform light distribution, and high brightness, with two colours possible and it is adaptable to different shapes.

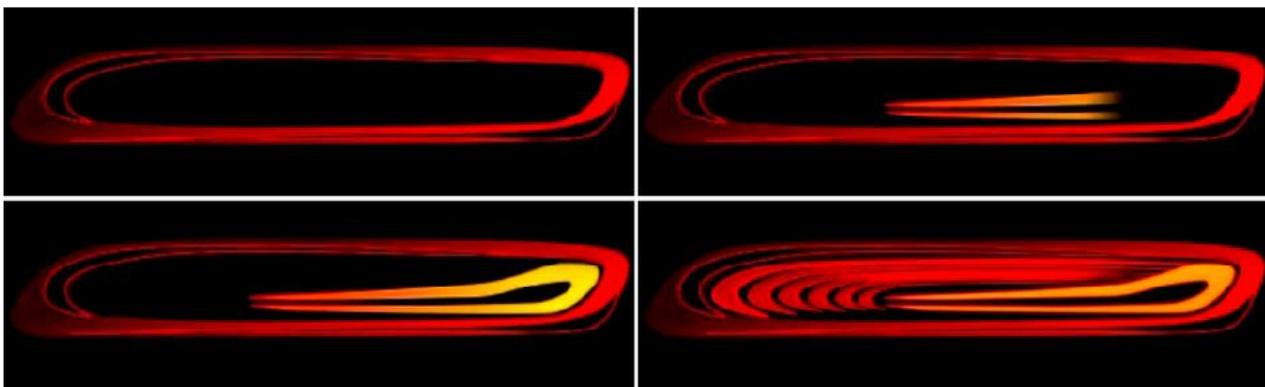


As to specifications for displays in rear lamps: at the last ISAL, Samsung presented a study showing that in outdoor condition, the resolution for good image quality must be less than 1.75 mm; the luminance to read

under bright sunlight must exceed 12,800 cd/m², and the viewing angle for pedestrian to recognise various information in display must be more than ±80°. Samsung put together a prototype with mini LEDs to these specifications and displaying different messages.



Samsung prototype with welcome, warning, autonomous driving, and electric charging



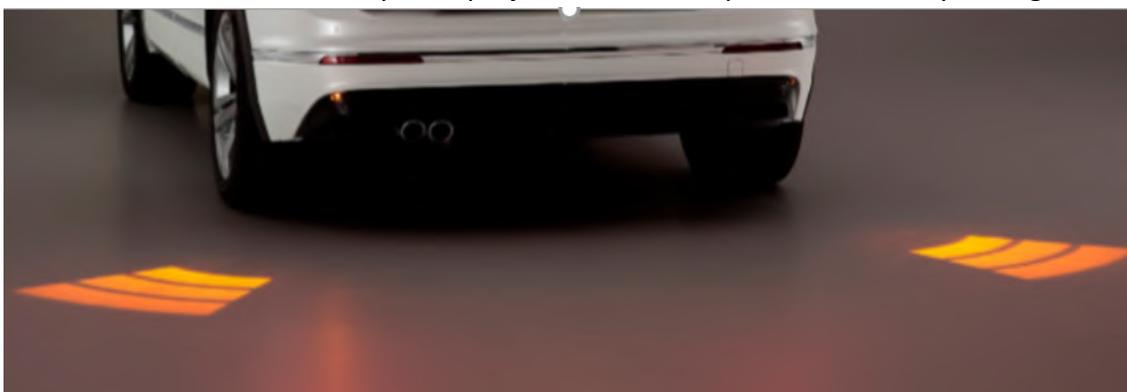
Same prototype used for traditional functions: tail, sequential turn half and full, and stop with turn indicator

However, for the future, μ LEDs are considered by many as a good potential technology for displays in rear lamps.

8.2 Road Projection

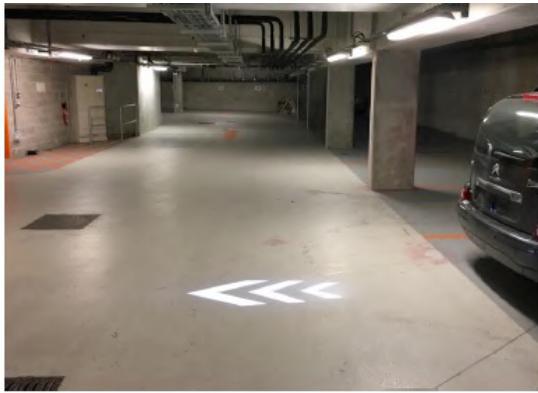
Road projection is also a promising technology, that could appear first as several studies are already completed for proposal to regulation authorities. The two first functions to be introduced will likely be road-projected turn indicators and road-projected reversing/departing lights as the studies for them have demonstrated their potential benefits.

For instance, turn indicator by road projection would expand the visibility during lane changing.



Similarly, road-projected arrows during reverse manoeuvre would inform others before seeing the reverse lights.

In the GTB study done by ELS, a projected white signal with a triple white arrow blinking with a 2 second period and with an illuminance of 2500 lx projected at the rear demonstrated an improved perception:



Other functions such as a "slow" or "stop" warning or an emergency signal can also be realised by road projection. And some years ago, Audi proposed an enhanced rear fog lamp with a transverse red line projected by a laser on the road, a safe distance behind the vehicle. In foul weather, the projection would form a red triangle (clearly a warning sign) in the air ahead of the following driver, plus the red line on the pavement. But in all cases, technical requirements must be decided, precisely defined, standardised, and then introduced into the regulations.



8.3 Integrated sensors

Cars have more and more sensors for ADAS and soon for autonomous vehicles. Cameras, radars, and compact lidars could take benefit of the favourable position of rear lamps at the corners to have a better angle of view and an anticipated information from the environment.



Future aspect for rear lighting with illuminated logo, 3D turn indicator, and sensors integrated (Valeo proposal)

9 · Conclusion

For many decades, rear lamps got rather less lavish attention than front lighting where many innovations were applied. At the rear, achieving the regulation was the primary main objective, and maybe there was some attentions to design, but relatively little money was devoted. LEDs with their grand styling and execution flexibility, combining all abilities for curvatures and long extension, for structural and decorated aspects, and for various light animations, have given the technical basis for a rear lighting ascendancy. Designers are now very involved to express a strong signature, and are budgeting specifically to improve the appearance of rear lights.

Through this report, we have seen that demands for style are numerous for these elements which so prominently characterise the rear signature of the car. Requests for originality and novelty will only carry on increasing. We have also seen that new technologies are appearing. Beyond wiping turn indicators, ARS, welcome scenarios, and OLEDs already present in the automotive world, displays and road projection are currently prepared. They will change the role of rear lamps, towards a device much more orientated towards active communication at a more granular level than ever before. Integration of sensors for ADAS and autonomous driving, and perhaps eventual LiFi communication will further extend the scope of the rear lights' job. The technical and styling journey of rear lamps is in an increasingly exciting and challenging phase!

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Materials in lighting
Laser Headlighting
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Volkswagen profile
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Integration of ADAS in Lights
IAA Frankfurt Auto Show
ISAL
Vehicle lighting in America
Interior lighting

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February – New car models from November 2020 to February 2021
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TactoTek, Finland
Texas Instruments, USA
Valeo, France, Spain, China
Weidplass, Germany
Yanfeng, Germany
ZKW, Austria

Set Makers-Tier 1s 32

DH Lighting, Korea
Elba, Romania
Farba, Turkey
Feka, Turkey,
FlexNgate, USA
Grakon, USA,
Grote, USA
Hascovision, China
Hella, Germany
Ichikoh, Japan
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Lightworks, Germany
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Magna, USA, Austria, Italy
Marelli, AL Germany, USA
Mind Opto, China
Myotek Industries, USA
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NAL, USA
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Nordic Lights, Finland
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Phoenix lamps, India
Plastic Omnium, France
SL Corporation, Korea
Stanley, Japan
Valeo, France, Spain, China
Varroc, Germany, Czech R.
Xingyu, China
ZKW, Austria
Zodiac, France

Light Source Suppliers 15

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Brightek, Taiwan
Cree, USA
Diodes Dynamics, USA
Dominant Opto Tech., Malaysia
Everlight Electr., Taiwan, Germ.
Excellence Opto., USA, Taiwan
LG Innotek, South Korea
Lumileds, Netherlands
Nichia, Japan
Osram, Germany
Samsung LED, Korea
Seoul Semiconductor, Korea
Sora Laser Diode, USA
Tungsramp, Hungary

Univ., labs, Consultants 20

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LAB, France
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Ansys, France
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