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Development Of Led Based Optical Module for Bending/Cornering Functions of Automotive Headlights

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Abstract – This paper presents applied physical proto results as a proof of technical concept of the patent: "Specific Lens design for Automotive Headlamps" (European Patent Office, Specific Lens design for Automotive Headlamps: European Patent Office, The Hague PCT/TR2020/051125; 11/2021). It includes the base explanations of bending/cornering lights features; the relevant European regulations; and then proposes the new idea with defined new optomechanical targets. It gets deeper with design of the new non-uniform surface lens in five different versions for which the patent is applied on version 5 and it continues with physical proto construction of the complete LED Module; assembly of the module in the automotive headlights; making the new module functional in the headlamp and finally giving the applied physical results with a night drive test.

Keywords *– Automotive headlights; fixed bending light/ fixed cornering light; non-uniform surface; optics*

I. Introduction

Today the design and performance of automotive headlights plays a critical role which impacts the customer perception by offering different driving modes. These driving modes also become as a safety feature while driving under hard weather conditions or dark zones which decreases the driver vision of visibility of the road and surroundings.

In this approach, bending and cornering light features inside the headlamps plays a crucial role for the safe and comfortable driving by giving assistance to have better visibility in tight bends, junctions, or parking conditions.

II. BENDING/CORNERING LIGHT FEATURES

Bending and cornering light features are used to create adaptive driving beams within headlights to create safety driving modes.

A. Bending Light Feature

Bending lights are used to illuminate the bends of roads.

There are 2 types of bending lights: dynamic and static bending lights. Dynamic bending lights use a motor to move the low beam PES module and create bending light. This design is not preferred today due they are expensive, heavy and high in volume. An example can be seen in Fig.1.

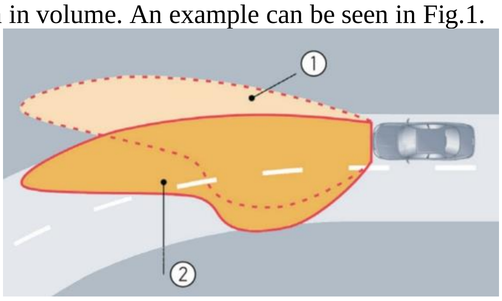

Fig. 1. Dynamic bending light (2)/ low beam (1)

Static bending lights are angled reflector designs within headlamps. They are also not preferred as their efficiency is not good enough compared to dynamic bending lights. Both solutions are mechanical designs. Bending light feature is lit on by switch of combi switch or is activated by steering wheel angle.

As indicated on UNECE R112, optical design of headlamps shall be so made that they give adequate illumination without dazzle when emitting the passing beam, and good illumination when emitting the driving beam. Bend lighting may be produced by activating one or more LED module(s) being part of the passing beam headlamp [1]. In table 1; a synthesis of bending light in terms of regulations can be seen.

Static Bending Light Regulation Synthesis	
Legislation area	ECE
Regulation number	R98/R112
Definition	*Part of low beam Legal since 10.12.2002 No specific photometry requirement Should illuminate under cut-off line
Mounting Regulation number	ECE R 48 Height: 500mm<x<1200mm
Switching	*Steering Angle *curve of radius<500m

Table 1. Static Bending Light Regulation Synthesis

B. Cornering Light Feature

As indicated in UNECE R119, cornering light is used to provide supplementary illumination of that part of the road which is located near the forward corner of the vehicle at the side towards which the vehicle is going to turn [2]. As indicated by Sullivan, the distribution of preview positions shows strong concentrations between 30 and 35 degrees to the right or left of the current direction of travel [3]. On Fig.2, additional illumination of cornering light can be seen with number 1.

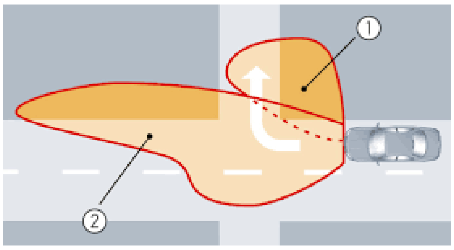

Fig. 2. Cornering light (1)/ low beam (2)

Following R119; for the left-hand device, the minimum intensity of the light at the specified measuring points shall be as follows: (1) 2.5D – 30L: 240 cd, (2) 2.5D – 45L: 400 cd, (3) 2.5D – 60L: 240 cd. The same values apply symmetrically for a right-hand device. The intensity of the light emitted in all directions shall not exceed 300 cd above the 1.0U L and R line, 600 cd on the horizontal plane 14.000 cd below the 0.57 D-L and R line. In the areas of 10◦ above and below the horizontal and between 30◦ and 60◦ outwards the light intensity shall be at least 1.0 cd [2].

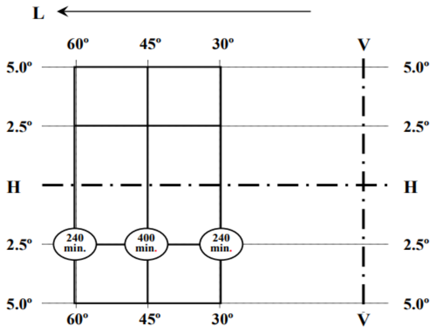

Fig. 3. Cornering light R119 photometry requirements

III. DETERMINATION OF DESIGN CONSTRAINTS AND TARGETS OF THE BENDING/CORNERING MODULE

In this section, major design constraints and targets are constructed. The main purpose to design this LED module is to create a bending/cornering feature by use of a statical optical solution in a compact, performance and cost-efficient manner.

A. *Optical Targets*

The optical constraint of the module is received from the regulation requirements mentioned in the previous section. However, the targets are defined to create further optical performance. It is aimed to achieve both cornering and bending features in this optical design. So, the optical target parameters are tailored based on this starting intention.

Luminious Flux			
200 lm			
Max Limunious Intensity			
3000 ± %10 cd			
Location in Horizonal Axe		**Location in Vertical Axe**	
[-40° ; -35°]		[-1° ; -3°]	
Efficiency of the optical System (Output flux / Input flux)			
%66 (200 lm / 300 lm)			
250 cd isolux line			
Horizonal Axe		**Vertical Axe**	
[-70° ; -65°]	[-15° ; -10°]	50 cd > 12° 250 cd : - 9° 1000 cd : -7°	0°

Table 2. Optical Performance target of the Bending/Cornering Modul

A. *Mechanical Targets*

Lens dimensions are determined as w:38mm XH: 24 mm X D:22mm. It is decided that the module will be positioned on the corner of the headlamp where TI function is located as can be seen red marked in Fig.4.

Fig.4 Location of FBL module in the headlamp

Additionally following mechanical positioning requirements are applied as an input to our optomechanical design during simulations:

- Driver's eye position (ground clearance): 1172 mm
- Driver's visibility starting distance: 5747 mm (From Bumper)
- Distance between left low beam and right low beam (in y-axis): 1311 mm = space between right and left bends
- Distance between left cornering light and right cornering light (in y-axis): approx. 1150 mm
- Low beam ground clearance (in z-axis): 713 mm (reference ground clearance)
- Ground clearance of the cornering light (in the z-axis): approx. 700 mm.

IV. DESIGN OF THE OPTICAL FIXED BENDING/ CORNERING LED MODULE

As the optical and mechanical limits and target are defined; it is started with the design the non-uniform collimating lens that will assure the targeted photometry requirements. To achieve the targets, 5 different design versions are studied.

In the different versions the main characteristics that made the differences were listed as following: the level good cut-off clarity; the smoothness of the transition from the low beam as supplementary illumination on the road and assuring the good combination of bending and cornering features. It is unacceptable to create any glare with the presence of a bright light, during which visibility is temporarily reduced [4].

The first version was rejected due to bad cut-off clearance on HV horizontal line, as can be seen in Fig.5

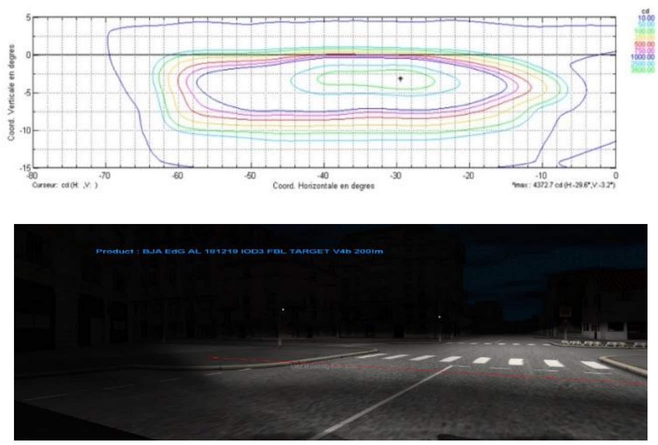

Fig.5. V1-Optical design

So, the second version with stable cut of clarity is generated as can be seen below in Fig.6. When this simulation output was examined, it was seen that the corner lighting was very wide. It was also found that the maximum light intensity (Emax) was quite low.

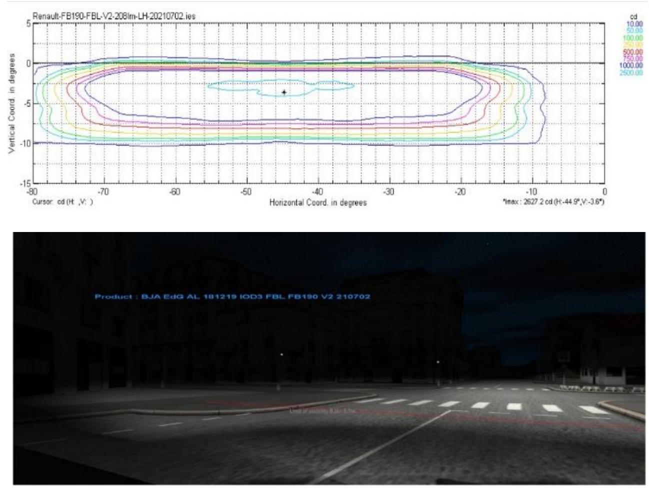

Fig.6 V2- Optical design

Following V3 design can also be seen below in Fig.7. In this version the maximum light intensity (Emax) value has been increased. However, the position where the maximum light intensity is seen is very outboard and not centred. It is indicated that for the comfort of driving, the light distribution generated on the street concerning luminance, contrast sensitivity and homogeneity are further parameters [5]. The version 3 design creates the risk of disconnection of the cornering/bending beam from the low beam.

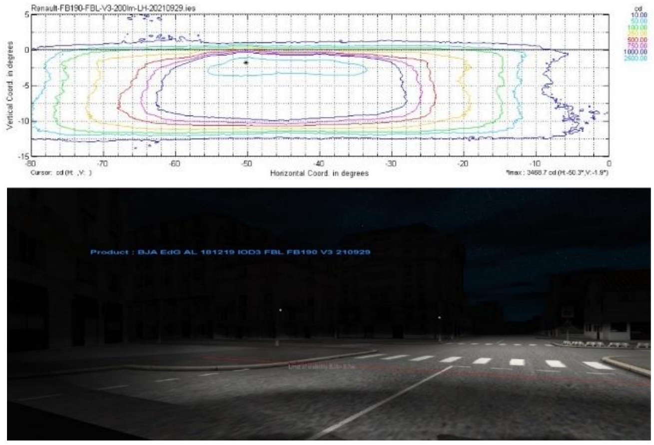

Fig.7. V3- Optical design

Accordingly, V4 design is produced as below on Fig.8.

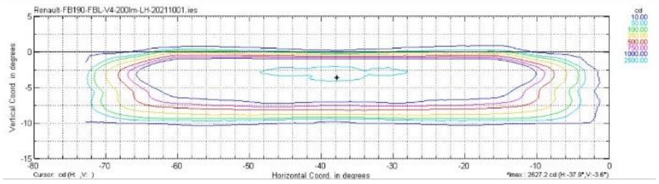

Fig.8. V4- Optical design

The performance of the lens was improved by changing the non-uniform surface angles of its prisms in line with the determined targets, and as a result, light was added to the bending/cornering zone. While this situation is positive, it is undesirable that the Emax is low and the overlaps with the low beam (LB) are too high towards in the front of the vehicle. The final design is completed with V5 version with details that can be seen in Fig.9.

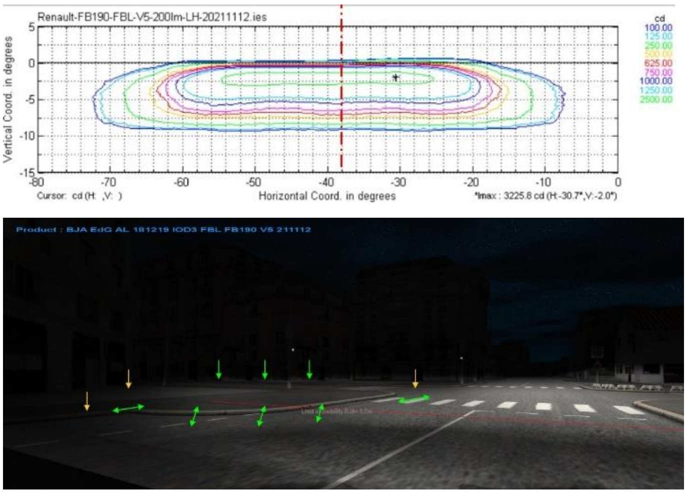

Fig.9. V5- Optical design

With this final version, the design assures following characteristics:

- Emax is centred around -40° within the symmetry conditions. Emax has a high vertical value.
- The upper limit is flat and 0°, good coherence with LB.
- Flux meets 200 lm target.
- The side transitions are softened, and the inner and outer regions are symmetrical.
- The outer limits at [-70; -60°] are not too wide, but sufficient for static cornering lighting.
- The vertical lower boundaries of the beam are regular and gradual. This ensures ideal operation for near-field lighting and fog cornering lighting.

Comparative status of all 5 versions can be seen in Table 3 in the following page. As can be seen; V5 final design is the best match to create a good combination of cornering and bending lights.

Criteria [targets]	**FB190 v1**	**FB190 v2**	**FB190 v3**	**FB190 v4**	**FB190 v5**
Flux [200 lm]	200 lm	208 lm	200 lm	207 lm	200 lm
Outer Limit [-70° ; -65°]	-61.5°	-77°	-73°	-70°	-68°
Internal limit [-15° ; -10°]	0°	-13°	-19°	-6°	-12°
9° down minimum	-15°	-9°	-11°	-8.5°	-9°
above 0° maximum	+0°	+0°	+0°	0°	0°
3000 ± %10 cd	4370 cd	2630 cd	3468 cd	2627 cd	3225 cd
Horizontal Position [-40° ; -35°]	-65°	-45°	-50°	-38°	-40°
Vertical Position [-1° ; -3°]	+5°	-3.6°	-1.85°	-3.6°	-2°

Table 3. Comparative table of all 5 version designs (V5 is best match)

Following on Fig.10, the iso-lux diagram of the final V5 version can be seen.

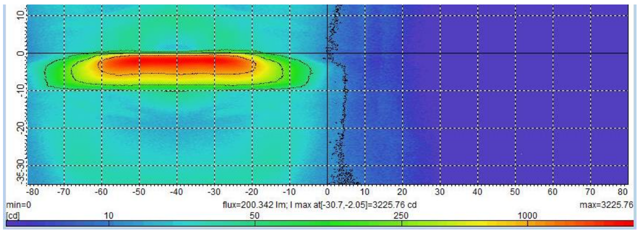

Fig.10. V5- Isolux Diagram

As can be seen in Table 4.; the cornering R119 requirements are assured and are OK.

```
Date       : Fri Jan  7 08:59:40 2022
LID name   : Renault_FB190_FBL_V5_2001m_LH_20211112.ies
Regulation: ECE R119 cornering lamp left

==========================================================================================
name            value OK      min       max              test pos.                found pos.
                 [cd]         [cd]      [cd]               [deg]                    [deg]
------------------------------------------------------------------------------------------

2.5D 30L       2959.6 OK    240.0       --       -30.00,-2.50
2.5D 45L       2928.8 OK    400.0       --       -45.00,-2.50
2.5D 60L       1172.4 OK    240.0       --       -60.00,-2.50
HH-1U L-R       409.9 OK      --       600.0     -60.00, 0.00 ;  0.00, 1.00     -29.70, 0.00
>1U             47.00 OK      --       300.0     -60.00, 1.00 ;  0.00, 90.00     -39.50, 8.75
<0.57D         3225.8 OK      --       14000     -60.00,-90.00 ;  0.00,-0.57     -30.70,-2.05
------------------------------------------------------------------------------------------
 The light distribution is OK
```

Table.4. V5- R119 Photometry Results of V5 Design: OK

When low beam and bending/cornering functions are merged below iso-lux diagram can be observed on Fig.11.

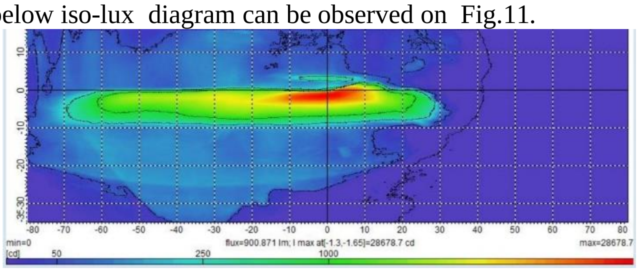

Fig.11. V5- Isolux Diagram (LB+ Bending/Cornering)

The driver view of the only low beam iso-lux diagram on the road can be seen in Fig.12. Low beam together with Bending/Cornering can also be seen in Fig.13.

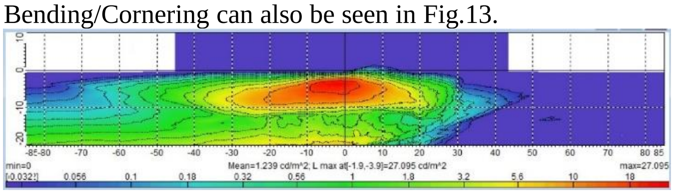

Fig.12. Driver view (Low Beam)

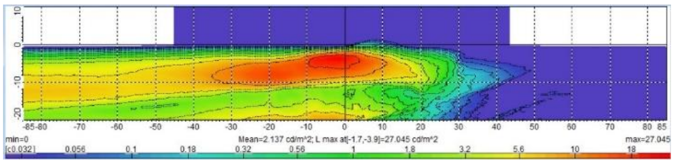

Fig.13. V5- Driver view (Low Beam+ Bending/Cornering)

We can observe the smooth transition from low beam to bending/cornering functions also on the grayscale distributions of driver view can be seen on Fig.14 and 15.

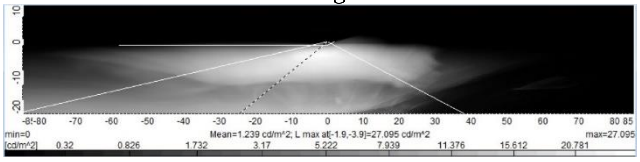

Fig.14. Driver view Gray Scale (Low Beam)

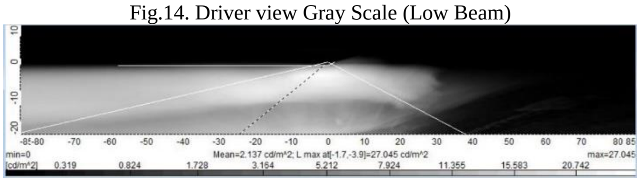

Fig.15. V5- Driver view Gray Scale (Low Beam+ Bending/Cornering)

On Fig.16. only the low beam distribution on the bend of a road can be seen. On Fig.17; it can clearly be detected the additional value of this design as a benefit of driving comfort.

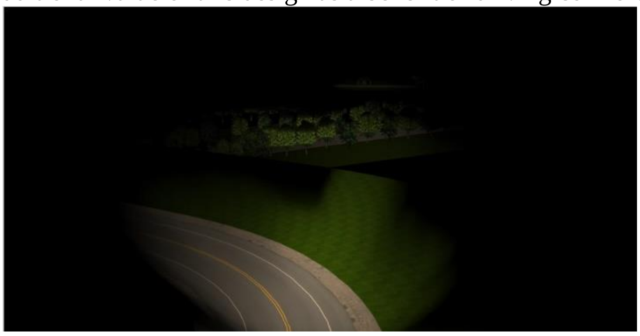

Fig.16. Real view on bend of a road (Low Beam)

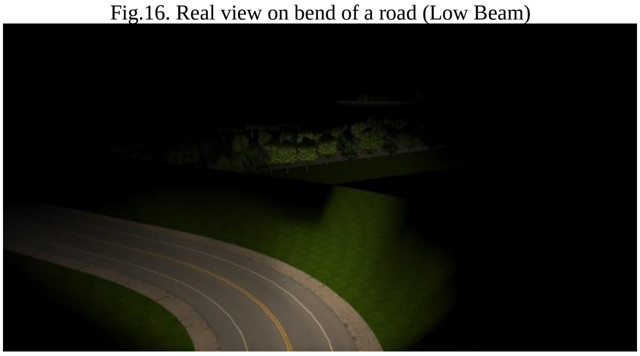

Fig.17. Real view on bend of a road (Low Beam+ Cornering/Bending)

Top view on the road for the same case can also be seen in following Fig.18 and 19.

Fig.18. Top view on bend of a road (Low Beam)

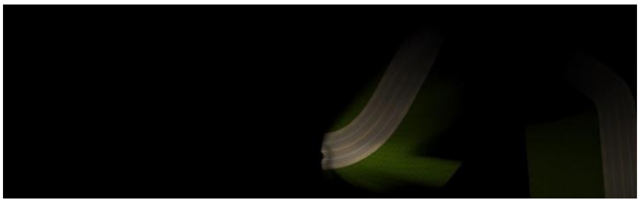

Fig.19. Top view on bend of a road (Low Beam+ Cornering/Bending)

V. FUNCTIONAL PROTO PRODUCTION OF THE BENDING/ CORNERING LED MODULE

After optical and mechanical design of the cornering/bending module is completed; a prototype of the below 3D on Fig.20 has been produced. On Fig.21 the isolux diagram of the simulation result can be seen.

Fig.20. 3D of the Cornering/Bending Module in the Headlamp

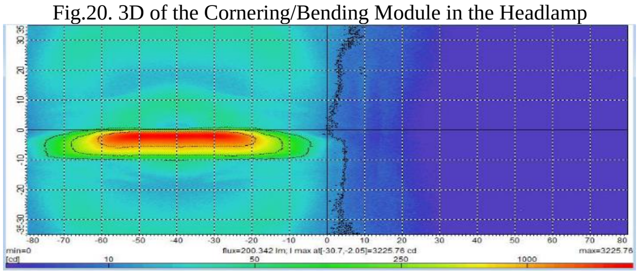

Fig.21. Isolux diagram of the simulation result

On Fig.22, the proto sample can be seen assembled in the headlamp. On Fig.23, we can see the IES file extraction from the goniometer test results as an Isolux diagram.

Fig.22. Functional proto of the Fig.20 3D

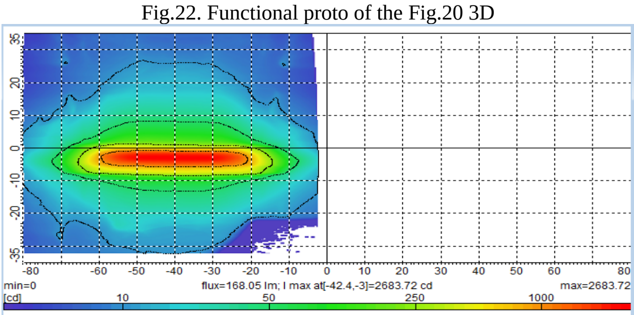

Fig.23. Isolux diagram of the functional proto

On Table.5; photometry table of left cornering function in simulation and on Table.6 photometry table of left cornering function in proto can be seen. Both results are OK in terms of ECE R119 requirements.

Date : Wed Mar 16 12:12:01 2022
Regulation: ECE R119 cornering lamp left

name	value OK [cd]	min [cd]	max [cd]	test pos. [deg]	found pos. [deg]
2.5D 30L	2959.6 OK	240.0	--	-30.00,-2.50	
2.5D 45L	2928.8 OK	400.0	--	-45.00,-2.50	
2.5D 60L	1172.4 OK	240.0	--	-60.00,-2.50	
HH-1U L-R	409.9 OK	--	600.0	-60.00, 0.00 ; 0.00, 1.00	-29.70, 0.00
>1U	47.00 OK	--	300.0	-60.00, 1.00 ; 0.00, 90.00	-39.50, 8.75
<0.57D	3225.8 OK	--	14000	-60.00,-90.00 ; 0.00,-0.57	-30.70,-2.05

The light distribution is OK

Table 5. Photometry table of left cornering function in simulation

Date : Wed Mar 16 12:10:53 2022
Regulation: ECE R119 cornering lamp left

name	value OK [cd]	min [cd]	max [cd]	test pos. [deg]	found pos. [deg]
2.5D 30L	2299.9 OK	240.0	--	-30.00,-2.50	
2.5D 45L	2521.3 OK	400.0	--	-45.00,-2.50	
2.5D 60L	905.0 OK	240.0	--	-60.00,-2.50	
HH-1U L-R	549.8 OK	--	600.0	-60.00, 0.00 ; 0.00, 1.00	-54.60, 0.00
>1U	299.0 OK	--	300.0	-60.00, 1.00 ; 0.00, 90.00	-55.00, 1.00
<0.57D	2683.7 OK	--	14000	-60.00,-90.00 ; 0.00,-0.57	-42.40,-3.00

The light distribution is OK

Table 6. Photometry table of left cornering function in proto

Following Fig.24-25 and 26 represents the Isolux diagrams of simulation of low beam only; simulation of low beam+ V5 design and test results of low beam+ functional proto V5 respectively.

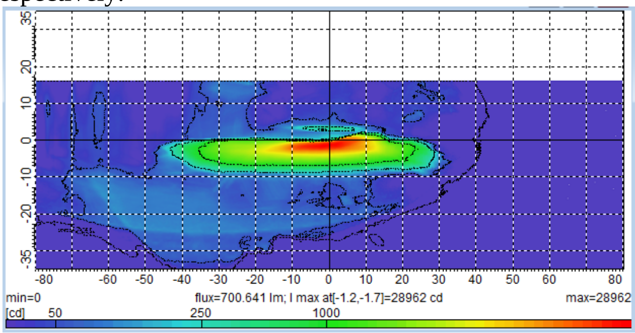

Fig.24. Isolux diagram of simulation of low beam only

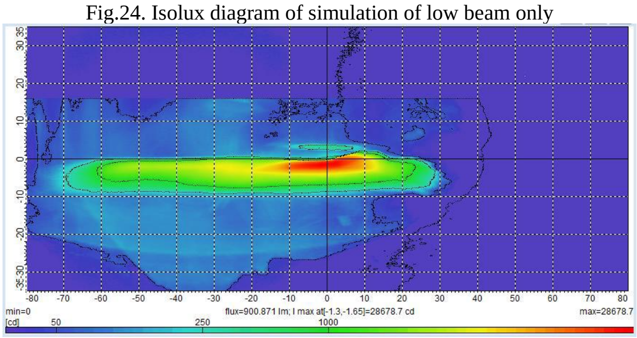

Fig.25. Isolux diagram of simulation of low beam+ V5 design

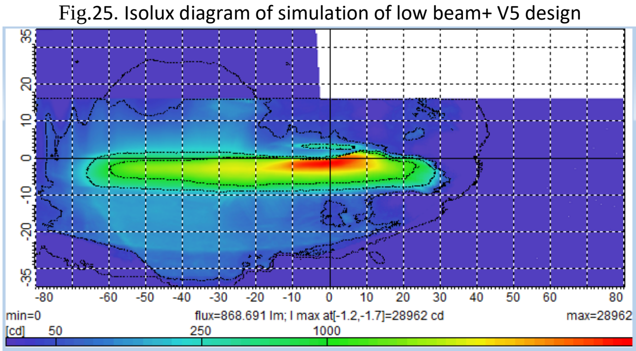

Fig.26. Isolux diagram of test results of low beam+ functional proto V5

Same study is done also for driver view status on the road; details can be found in the following Fig. 27-28 and 29.

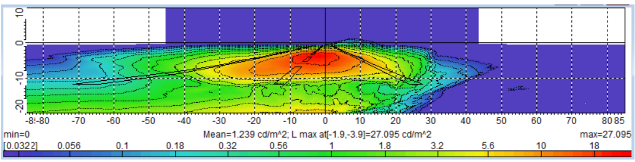

Fig.27.Driver view simulation of low beam only

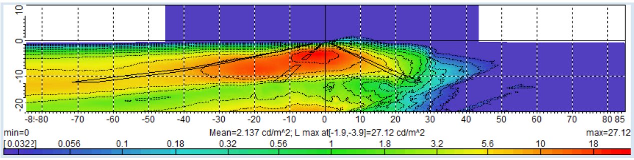

Fig.28.Driver view simulation of low beam only+ V5 design

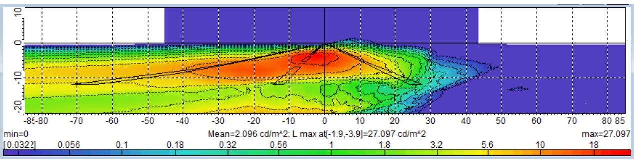

Fig.29. Driver view of test results of low beam+ functional proto V5

The grayscale version of the same above Isolux diagrams can be seen in Fig.30-31 and 32 respectively.

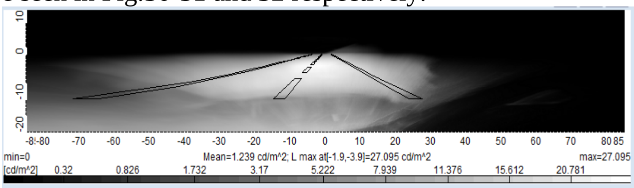

Fig.30.Gray scale driver view simulation of low beam only

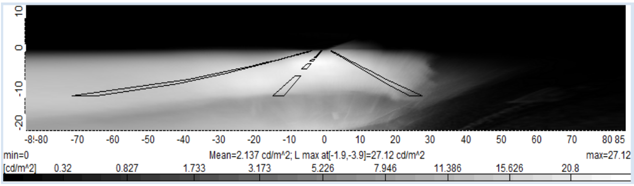

Fig.31.Gray Scale driver view simulation of low beam only+ V5 design

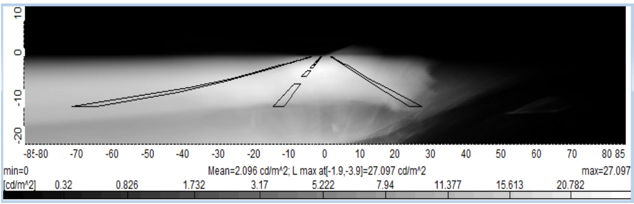

Fig.32.Gray Scale driver view of test results LB+ functional proto V5

Criteria	Simulation	Mockup Measurement
Input LED Flux	373 lm	341 lm
Output Headlamp Flux inc. headlamp outer lens transmision loss 15%	200 lm	168 lm
Optical System Efficiency (output Flux / input Flux) %	53% (200 lm / 373 lm)	49% (168 lm / 341 lm)

Table 7. Efficiency calculation between simulation and proto measurements.

Accordingly, as calculated on Table.7 the optical module efficiency is reduced from 53% to 49%. As a result of the examinations, it was understood that this difference of 4% loss of efficiency was due to the low level of polishing, and it naturally originates from the production of the prototype material. However, this situation is specific to the prototype part and will be solved with serial tool production where we can apply mirror polish surfaces without impacting the optical efficiency.

We can see the bending road distribution on Fig.33,34,35 as following: Simulation Low Beam; Simulation LB + V5 Cornering/Bending module and Real LB + V5 Functional Proto Measurement respectively.

Fig.33. Simulation Low Beam distribution on the bending road

Fig.34. Simulation LB + V5 Cornering/Bending module

Fig.35. Real LB + V5 Functional Proto Measurement results

The cornering road distribution can also be found on Fig.36,37,38 as following: Simulation Low Beam; Simulation LB + V5 Cornering/Bending module and Real LB + V5 Functional Proto Measurement respectively

The cornering road distribution can also be found on Fig.36,37,38 as following: Simulation Low Beam; Simulation LB + V5 Cornering/Bending module and Real LB + V5 Functional Proto Measurement respectively

Fig.36. Simulation Low Beam distribution on the corner

Fig.37. Simulation LB + V5 Cornering/Bending module on the corner

Fig.35. Real LB + V5 Functional Proto Measurement results on the corner

As a result, of this section; we have well seen the additional value of the new designed cornering/bending module in comparative manner between simulations and real measurements. Taking into account the expected improvement of efficiency in serial production; the test results obtained by producing this design as a prototype also gives results in parallel with the simulation and is sufficient to meet the requirements.

In this regard, the lens, which was designed and analyzed with the LucidShape program with five versions of which were developed with gradually better results, was physically obtained with prototype production; assembled in the headlmap and brought ready as functional on the vehicle.

VI. NIGHT DRIVE TESTS WITH THE FUNCTIONAL PROTO OF THE BENDING/ CORNERING MODULE

Within this section; we are focused on the functional proof of concept by performing the night drive test for the officially applied patent idea.

Below on Fig.36 we can see functional status of the cornering/bending light in the inboard corner of the headlamp.

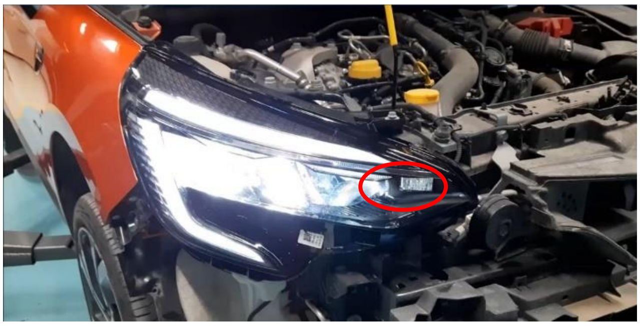

Fig.36. The image after the installation of the cornering/bending module to the vehicle

The on road on and off status of the cornering/ bending light module can be seen respectively on Fig.37 and 38. The additional light out put created by the cornering/bending module on the side of the road can be seen as marked in the red square. The dark zones which exist while only low beam is on; are smoothly filled by the addition of the lit on of cornering/bending module. This realization shows that the new designed module has the potential to become a feature of additional drivimg mode as a complementary of low beam.

Fig.37. Night Drive test: only low beam

Fig.38. Night Drive test: low beam+ cornering/bending module

As the cornering/bending light is lit on; another additional benefit is realized which is easy detection of passangers, animals or any other possible obsticles on the side of the road that the driver can not detect while this cornering/bending light is not lit on. So the Cornering Light enables drivers to see obstacles in good time and take the appropriate action which ensures greater comfort and safety [6]. On Fig. 39 and 40 the night drive test results for comparative status of the lit off and lit on status of cornering/Bending LED module can be observed.

Fig.39. Night Drive test: only low beam

Fig.40. Night Drive test: low beam+ cornering/bending module

DISCUSSION

As a synthesis on Table.8; the comparative status between input target; V5 Sim Results and final proto test results can be observed.

Criteria	Optical Input Targets	V5 Simulation Results	Prototype Test Results
Flux	200 lm	200 lm	168 lm
Exterior Limit	[-70°;-65°]	-68°	-66°
Interior Limit	[-15°;-10°]	-12°	-14°
9° down max	-9°	-9°	-9°
0° up max	0°	0°	0°
[3000;5000] cd	3000 +/-10%cd	3225 cd	2683 cd
Horizontal range	[-40°;-35°]	-40°	+38°
Vertical Range	[-1°;-3°]	-2°	-3°
Efficiency		%53	%49
Number of Led	1	1	1

Table 8. Comparative table between input target; V5 Sim Results and Proto test results

When the Isolux diagrams on Fig.24 and 25 are evaluated, it is seen that the light intensity distribution is similar. However, while the maximum light output value of the simulation was 3225.76 cd, the maximum light output of the prototype is determined as 2683.72 cd. Exterior limit is also reduced from -68◦ to -66◦. The lost in efficiency is considered due to below facts:

- 4% difference in simulation and mockup measurement results comes from the lack of the polishing of the light mockup optical surfaces.
- Since it is PMMA plastic material, it is not possible to do 100% high gloss polishing. If high gloss polishing is applied; it may destroy the optical surfaces of the plastic material and might cause non-uniform surface design to be damaged.

CONCLUSION

The final out come test results are in paralel with design and simulation results. %4 efficiency difference is determined to be expected as in serial devolepment, the hard tools surfaces will be steel and it will be possible to 100% high gloss polishing without any risk. Accordingly the light transmission of the collimator's optics surfaces will be higher than the mockup and it is assumed that the target flux output in the simulation will be assured. To sum up; this paper declares all the R&D study sourcing from the patent idea and it expands with succesfull technical proof of concept with relavant simulations and test results.

In conclusion; the aim of AFS-Adaptive front Lighting Systems is to adapt light dsitribution on to the road to give optimum lighting performance in a range of driving situations [6]; and the characteristics of the optical statistical designed LED Module in this paper has a high potential to create different driving modes with the safety and comfort driving features to illuminate bending and cornering roads.

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REFERENCES

1. GAR | UN R112 [WWW Document], n.d. URL https://globalautoregs.com/modifications?rule_id=123 (accessed 10.10.22).
2. CAR - Consolidated Automotive Regulations [WWW Document], n.d. URL https://www.consautoregs.com/unece/un-r119-rev-1 (accessed 10.10.22).
3. Sullivan, J., Flannagan, M., 2013. Vehicle Kinematics in Turns and the Role of Cornering Lamps in Driver Vision. LEUKOS J. Illum. Eng. Soc. N. Am. 7, 263–271. https://doi.org/10.1080/15502724.2011.10732151
4. Nighttime Glare and Driving Performance: Research Findings [WWW Document], n.d. URL https://www.researchgate.net/publication/216817082_Nighttime_Glare_and_Driving_Performance_Research_Findings (accessed 10.17.22).
5. Hamm, M., Lampen, M., 2000. Safety and Comfort: Advanced Methods to Analyze Headlamp Light Performance. https://doi.org/10.4271/2000-01-0320
6. SMART Cornering Light | HELLA [WWW Document], n.d. URL https://www.hella.com/soe/de/Produkte/Product-detail-4957/ (accessed 10.17.22).
7. Valeo Lighting Systems - From light to advancedvision technologies - [PDF Document] [WWW Document], n.d. . vdocuments.net. URL https://vdocuments.net/valeo-lighting-systems-from-light-to-advancedvision-technologies-.html (accessed 10.17.22).