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Vertical Designs for RID Solutions: Challenges for Legal Requirements and Consumer Ratings

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1. Abstract

For many years headlamp designs were guided by the size and shape of main light reflectors. With the change to modern projection module systems, this dynamic shifts more and more. Now main light are also subordinate to the general design of headlamps and cars. With this change, new challenges arise. Low width and height requirements of the projector lens a-surface lead to reduced efficiencies or reduced output per lens area. At the same time, increased focus on customer ratings increases performance requirement. Therefore, headlamp setups are built using multiple projector modules to generate one main light function. These modules must be aligned to each other – especially for lowbeam aiming. Headlamps with two modules with horizontal offset that contribute to a low beam function usually don't pose a big challenge, due to combinations of foreground and kink modules and generally larger tolerance windows in horizontal aiming. But the more modules are involved in the light function, contributing to gradient and kink generation, the more complicated design of the setup and aiming gets. And especially modules with vertical offset pose challenges, not just for consumer ratings, but even legal definitions, due to possibilities of generating multiple cut-offs and differences in measurement distances. To discuss these challenges, specific examples will be shown and explained how they are handled with vertically stacked modules. The impact of aligning cut-offs at different distances and decisions on legal definitions will be the main focus for best performance, with special focus on interaction between FMVSS legal requirements and IIHS rating evaluations

Keywords: projection module adjustment, consumer ratings,…

2. Introduction

Over the last years, a big challenge in development of new projection modules has been a strongly increased pressure from the overall vehicle design languages. While a few years

ago, design of main light projection modules was mostly limited to different shapes of module bezels, covering parts of the lenses, now these modules are an integral part in many headlamp designs. There are increasing possibilities in adjusting sizes and lens shapes, which in turn allows designers to lean into unique designs that are not only visible in daytime, but also stunning in night time [1].

Horizontal designs are currently more common for main light settings. Adjustment of these horizontal setups has already been implemented for several years. Vertical alignment of these modules is straight forward, as they are generally on a similar height. Horizontal alignment between these projection modules is also not too complicated, as the main feature to adjust is usually the inclined kink area for range and maximum intensity. This feature is often just present in one of the contributing projection modules. The horizontal adjustment range is therefore in most cases up to a degree, without a big impact, and in some cases, with a mix of only one kink module and one or more foreground modules, could provide legal light distributions even for large misalignment.

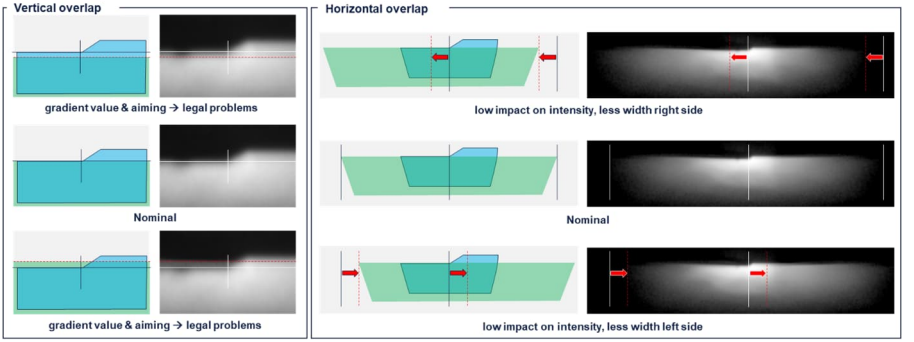

Figure 1: Impact of vertical (left) and horizontal (right) misalignment for a simple two module setup. Vertical mismatch of a cut-off has much bigger implications than horizontal misalignment due to the direct impact on the cut-off quality and gradient. Horizontal offset between light distributions has lower impact, mainly reducing maximum intensities in the center of the distribution.

Vertical designs, on the other hand, are much more complicated to align. Vertical alignment is strongly impacting the legal gradient position. Even small mismatches shift the gradient with respect to maximum intensity of the overlayed light distribution or cause double gradients (See figure 1). Therefore, deciding how and where to overlap the light distributions from projection modules with vertical offset is an important step in any development of vertical designs. In addition, a vertical setup of modules is often the result of a design decision. This usually also comes with narrow horizontal lenses and accordingly low performance per lens area and the requirement of using several modules instead of just two or three. In the following chapters we will focus on the overlap of three

modules with higher intensity around the central cut-off, which might be combined later on with lower intensity width focused modules.

3. Alignment considerations

Depending on which legal requirements apply to a specific project, gradient is measured at 10 or 25m distance to the headlamp. In FMVSS, for example, legal gradient measurement of low beam (LB) is evaluated at 10m, while photometry of LB points is evaluated at 25m. If two modules are positioned 5cm vertically apart and aligned straight ahead, the angular distance between cut-off at 10m would correspond to 0.286°, and 0.115° at 25m. Thus, especially at 10m distance, the parallel aiming has a significant impact on the gradient alignment.

An important thing to note here, is that standard intensity sensors, used in many simulations during development, evaluate raytracing in the far field (infinity). Having stacked modules aligned parallel will give a perfect light distribution for these intensity sensors, as the module offset is negligible in these simulations. I.e., impact on the near field needs to be investigated specifically and can easily be overlooked if there are no processes defined to evaluate these systems.

It is important to consider different factors for the aiming:

- Center point of the lamp
- Necessity of converging aiming to a certain distance
- Additional factors outside of legal requirements to the aiming

The definition of the center point for vertically stacked modules is important because, as mentioned before, the impact at 10m distance for gradient evaluation is strongly influenced by the module distance. Choosing the center point higher or lower might cause a lamp to be adjusted up or down with a gradient measurement at 10m. Figure 2 shows three different alignment concepts for a stack of three vertically off-set projection modules. Table 1 shows a comparison of gradient position for concepts 1 and 2 with different center points. If the center point is positioned at the same height as the bottom module, the gradient position between 10 and 25m of the combined light distributions shifts by over 0.31° for both aiming concepts. If the center point is chosen at the height of the central module, the gradient position between measurement of 10 and 25m changes by less than 0.2° in comparison, independent of concept. In the far field, results for any center point are the same, and just depend on the aiming concept.

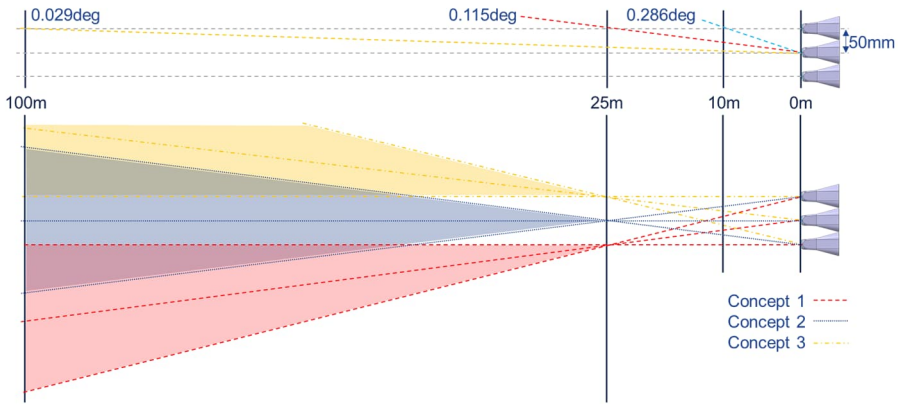

Figure 2: Vertical alignment strategies. The top side of the image shows parallel alignment of three vertically stacked projection modules and the corresponding angular offset at 10 and 25m distance. For a distance between two single modules of 50mm, the cut-off and gradient would be offset by ca. 0.286° at 10m (ca 0.5%). At 25m this offset is only 0.115°. The lower side shows converging aiming to a vertical spot at 25m at the height of each of the initial modules. Modules above the aiming point lose range on the road (case 1), while modules below the aiming point can cause glare at increasing distances from the vehicle (case 3).

Converging aiming at a certain distance can improve legal evaluation. If the projection modules are aimed straight ahead, the cut-off and maximum are not overlapped. This can have some legal impacts, like higher intensity in straylight points or lower limits for intensities that are dependent on the light maximum intensity. Aiming all modules to one point at 25m removes this problem and also reduces offset of gradient at 10m. Aiming at 10m would cause a big spread of light distributions at 25m. In addition, the legal gradient value can be heavily impacted by the alignment. As seen in the example in table 1, legal gradient values at 10m would be much lower due to cut-off offset than at 25m, where the cut-off positions are overlapped, causing a “better” image.

Additional factors outside of legal requirements are range, glare and homogeneity of the light distribution. Aiming at a vertical point at the height of the lowest contributing module means the other modules are aiming downwards. Therefore, while maximum intensity is good at 25m, the range of road illumination is reduced compared to parallel aiming, as seen in concept 1 of Figure 2. On the opposite site, for a higher aiming point, the lower modules are pointed upwards. At higher distances the cut-off of the lower modules is closer to eye height of oncoming drivers, with a high probability of glaring other road users, as seen in concept 3 of Figure 2. Different aiming can thus be disadvantageous for the driver of the vehicle or even dangerous for surrounding traffic with even a task force established for glare prevention in the UN-ECE[2]. So even having perfectly legal measurements at 25m, this needs to be extensively considered during

development. In addition, as mentioned before, homogeneity of the light distribution can be impacted by different aiming schemes, though the impact is usually lower than impact on range and glare. In most cases, the slightly different range of the single light distributions on the road improves softer transitions in the field of view, blending areas of higher and lower intensity.

		Gradient					
		10m		25m		Far field	
		Position	Value	Position	Value	Position	Value
Bottom	Concept 1	+0.31°	0. 35	**0.0°**	0.65	-0.05°	0.42
	Concept 2	+0.41°	0.37	+0.13°	0.62	+0.05°	0.47
Mid	Concept 1	+0.01°	0.34	-0.14°	0.66	-0.05°	0.42
	Concept 2	+0.15°	0.37	**-0.04°**	0.65	+0.05°	0.47

Table 2: Example of gradient position and value difference for a stack of three modules with 2 different aiming concepts (aiming in front of bottom module is concept 1, aiming in front of central module is concept 2) and two different center point definitions. For center point position at the height of the bottom module, the change of gradient position measured at 10m compared to 25m changes a lot more, than for center point defined in front of the central module.

4. Consumer ratings and performance requirements

Consumer ratings are designed to improve driving safety. Range and glare requirements are therefore especially relevant in various consumer rating evaluations and require optimized performance of headlights [3]. As an example, with relatively high range requirements, and clear glare definitions, an evaluation based on the Insurance Institute for Highway Safety (IIHS) rating [4] is used.

For the road illumination part of the IIHS rating, different range sensors on the left and right side of the road in different road scenarios are used to gauge the minimum reach the low and high beam distributions. As explained above, aiming higher improves the range rating, but at the same time there is a higher chance of glare demerits. Glare demerits increase very fast for higher glare levels. Therefore, usually avoiding glare demerits is more relevant than focusing on the best possible range.

Parallel aiming at first glance might have similar results on IIHS rating, as single module setups have, as the bigger part of distances for the measurements are large compared to the module offset. In more detail though, there is a big impact of height placement of the single contributing modules compared to the sensor height. But due to the various

influences, and previously discussed problems to legal evaluations, we will not discuss impact of parallel aiming and its impact on IIHS demerits.

To evaluate IIHS rating performance during development, without actual driving tests, virtual evaluation of the optical performance in a headlamp can be done with projections of the light distribution. For most headlamps, using an ies file of the final light distribution works well for this task. For vertically stacked modules, we run into the same issues as discussed before: at different distances in front of the car, the overlap of the single beam patterns is changing, depending on the aiming of every single contributing module. Omitting this step can lead to very different results from a real driving test.

Degree		-0.4	-0.3	-0.2	-0.1	0	+0.1	+0.2	+0.3	+0.4
Bottom sensor	Case1	23.5	17.3	12.5	9.2	7.1	6.1	6.2	6.2	20.9
	Case2	17.9	13.5	9.8	7.5	5.9	5.9	6.1	17.3	69.9
	Case3	10.7	8.1	6.3	6.1	6.2	6.6	42.1	100.6	165.0

Table 2: Example of IIHS rating demerits for different aiming concepts of three vertically stacked modules. Generally, aiming higher yields better range results, i.e. case 1, which has modules generally aimed down, has the worst score with most demerits in nominal headlamp position. In addition to nominal evaluation, vertical adjustment range has been included in the evaluation, for misalignment of the complete headlamps.

Table 2 shows the impact of the three different aiming concepts from figure 2 on the IIHS rating demerits. Evaluations for this example table have been set up using six (three each left and right) source positions, aiming the single beam patters according to the concepts shown in figure 2.

Aiming downward with case 1 would give a higher demerit value in nominal headlamp alignment, but more tolerance in the direction of upward swivelling. Aiming in front of the central module in this example would yield a similar tolerance in both directions of mis-aiming. Aiming upward would yield the best range in nominal setting and downward tolerance of the headlamp, but cause glare for any even slightly higher adjustment of the headlamp. In addition, it is directly visible that glare demerits are higher and increasing much faster than range demerits. So, tolerance in misalignment against glare is of very high importance, especially in a system with an increasing number of vertically stacked modules or higher distances between the modules.

5. Alignment & Reference measurements

After all aiming directions are defined, the last step is to define how to adjust the single contributing modules in-line and how to adjust the headlamp in general. In both cases, the same problems as before apply: depending on how far away the sensor is, or what kind of telescoping is used, there are different angular or millimeter offsets between each light distribution.

In-line adjustment and testing is usually done in shortened setups, using lenses or a lens system to project the cut-off quality that is usually achieved at 25m instead in a distance of only one meter or less. As the lens is so close to the modules, the offset in projection is much larger in this setup, compared to the actual 25m measurement setup. Angular adjustment, offset and measurement possibilities need to be considered during development to position modules correctly during production. In the next step, a concept to adjust the whole lamp in the car is necessary – in factory as well as service. Adjusting a headlamp on a wall at a few meters distance with several overlapped cut-offs would, depending on the alignment of modules, very likely be adjusted too low. At this distance, the various cut-offs of the single modules are visible as single misaligned cut-offs, if all modules are on. The upper-most visible cut-off - from the top module - is most likely aimed down, so the cut-off is too high up at 3 meters and the light distribution would be aimed too far down to counteract this height difference. The best way to adjust a headlamp with several fixed projection modules is therefore to use a mode with only one active module. Selection of this module is dependent on aiming of the single modules in the stack. The easiest solution is to select a module that is aimed parallel, to not need any further specific instructions. An example of this is shown in Figure 3, which shows one of our headlamps with vertical setup and the module that is selected for vertical adjustment in the car.

Figure 3: Setup in one of our serial headlamps with vertically stacked modules. For adjustment of the headlamp only the yellow marked module is used.

6. Summary

Combining legal requirements and consumer ratings, many conditions must be taken into account when developing a headlamp with several, and specifically vertically offset modules. Simplifying the setup in a way, to not require vertical aiming to a single height, and instead using parallel alignment is certainly the easiest, but not always feasible. With smaller or thinner designs, more lower intensity contributors have to be taken into account and a good aiming strategy is of the essence. While the examples used here focus on single stacked modules, the same concepts are relevant for any modular concepts like micro lens arrays, if they have a larger vertical spread. As shown, different aiming concepts have advantages considering range or safety for surrounding traffic, and it is essential that they are correctly evaluated during development.

7. References

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