Projecting a micro-LED matrix headlamp: beam intensity, pixel separation and the dark zone around an oncoming car

256 × 64 pixels on a 50 µm pitch, imaged by the three-lens projection lens of patent US 11428378 (f = 30.4 mm, f/0.67), judged against UN Regulation No. 149

The design problem

In a micro-LED headlamp, each of several thousand pixels can be switched on or off. With all of them lit, the module gives a driving beam. When a car comes the other way, the pixels aimed at its driver are switched off. The projection lens blurs each pixel, so some light of the lit pixels still reaches that dark zone. Lens design describes the blur by a spot and an MTF in the matrix plane, whereas UN Regulation No. 149 sets limits in candelas at given angles on the road. To check these limits, the light of the pixels has to be traced through the lens to the road.

How the system is modelled

The lens is entered from the tables of patent US 11428378, aspheres and stop included. The matrix is a source of 16 384 Lambertian emitters, 45 µm square, 0.4 lm each, and any set of pixels can be switched off. The rays leaving the lens are collected by direction into an intensity map in candelas. The regulation is read on that map. Each reading carries an error bound (three standard deviations of the Monte Carlo noise, plus the spread of the neighbouring cells). A requirement is met if the whole bound respects the limit, not met if it violates it, and undetermined otherwise.

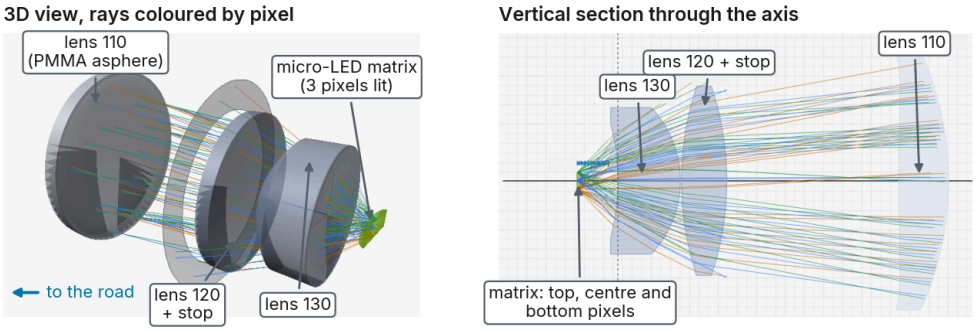


Figure 1. The model in etendue, with three pixels lit at the top, centre and bottom of the matrix. Each colour follows one pixel, from the matrix on the right towards the road.

What the analysis shows on the starting design

One module with all pixels lit reaches a peak of 59 000 cd, above the 40 000 cd minimum of a class B driving beam. All 11 driving-beam requirements of the regulation are met, error bound included. The blur of the lens, however, is large compared with a pixel. The RMS spot diameter on the matrix is 1.7 pixel pitches at the centre and 6.3 at the left and right edges. A lit pixel at the centre should light a square of 0.094° on the road; it puts 20 % of its light there, 10 % in the square of the next pixel, and spreads the rest further out. Its own square is on average 1.3 times brighter than the brightest point of the next square, whose pixel is off.

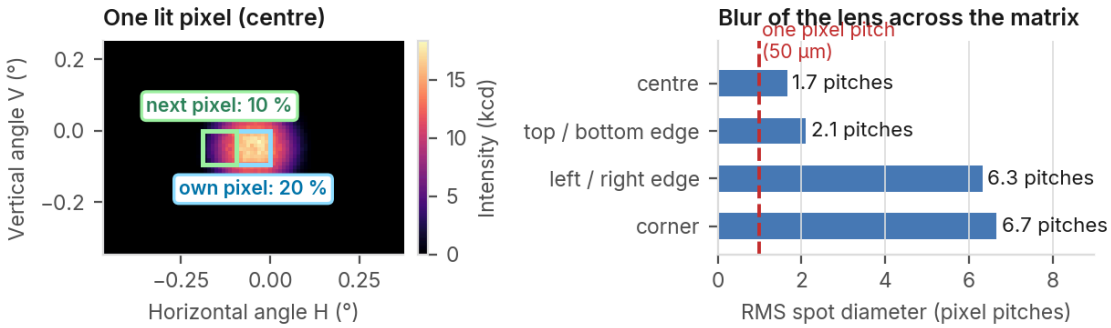


Figure 2. Left, intensity of one lit pixel computed by etendue, with its own angular square (blue) and that of the next pixel (green). Right, RMS spot diameter on the matrix (lens design model, 588 nm).

The driving beam

With all 16 384 pixels lit, the beam covers 24.6° by 6.1° and peaks at 59 000 cd. All 11 driving-beam requirements are met, error bound included; the point straight ahead on the horizon reaches 0.99 times the peak.

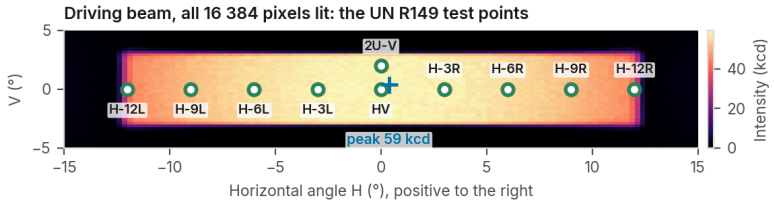


Figure 3. Intensity with all pixels lit, computed with etendue, and the UN R149 class B test points (green: met).

The dark zone for an oncoming car

For an oncoming car at 50 m, the regulation allows 625 cd on a line through its driver's eyes. Switching off just the pixels aimed at it leaves up to 37 338 cd on it: the blur of the lit neighbours spills in. With three more columns off on each side (0.28° of beam), the line reads 28 cd, its error bound stays below 524 cd: met. With the stray light of a real module (four more columns), the line reads 537 cd, below the limit (756 cd, above, with a more dispersive PMMA): undetermined, as the largest single ray alone sets a bound of 1 616 cd and the cells next to the line read up to 920 cd. A ±2σ estimate of the noise alone (not a guarantee) reads “too few rays”.

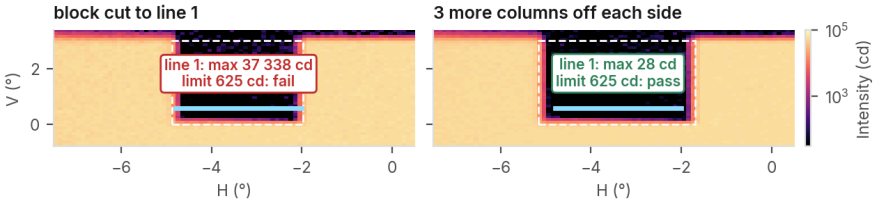


Figure 4. Intensity around the dark zone (log scale). Blue: the regulation line; dashed: the pixels switched off.

Light on the road

A flat detector 0.65 m below the lens stands for the road. The beam reaches it from about 12 m ahead; the illuminance peaks at 15 lx at 13 m, and on the axis 1 lx reaches 33 m. The dark zone for the oncoming car aims above the horizon: switching it off changes the light on the road beyond 10 m by 0.05 %.

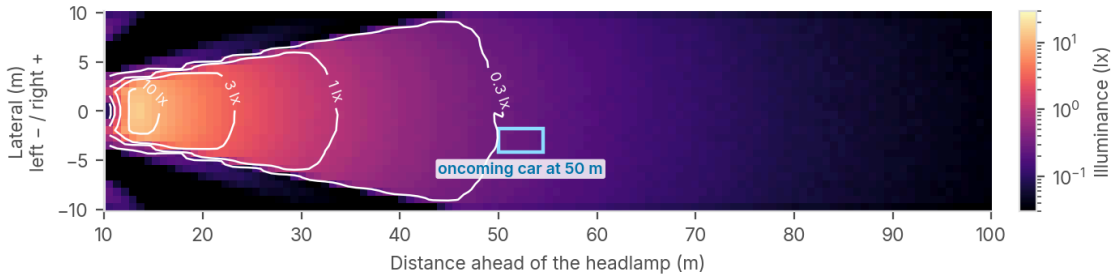


Figure 5. Illuminance on a level road seen from above, true scale, module 0.65 m high. White: equal-illuminance lines.

One plastic, and limitations

All three lenses in PMMA, radii re-optimised: at 550 nm the central RMS spot diameter grows from 95 to 711 µm. One wavelength, 555 nm, for the maps of the ideal module. 0.4 lm per pixel is 63 cd/mm², below the 75–100 published [3]. No heating of the matrix.

Reliability of the results

CHECK	REFERENCE	MODEL
f-number on axis	0.6 to 0.85 [1]	0.67
First to last lens face	54 to 76 mm [1]	61.17 mm
Back focal distance at best focus	7.52 mm [1]	7.52 mm
Total field	14–40° × 5–10° [1]	24.6° × 6.1°
Projection ratio, field H / V	2.5 to 6 [1]	4.0

References. [1] Patent US 11428378 B1, example 1. [2] UN Regulation No. 149, 01 series, § 5.1.4 and § 5.3. [3] Data sheets of automotive micro-LED matrices, 40 µm pitch.