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# ADAPTIVE LIGHTING SYSTEMS: TECHNICAL SOLUTIONS AND A METHODOLOGICAL APPROACH FOR PHOTOMETRIC SPECIFICATIONS

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## Introduction

Safety and comfort, during driving conditions, are becoming more and more demanded from the market even for medium-low class vehicles. The headlamp, and hence the visibility improvement during low light conditions, is one of the components or devices of a vehicle on which there is a strong activity in Europe, also in the frame of the EUREKA 1403 project, and in Japan in order to have a more effective and flexible light utilisation. Market surveys have revealed that drivers demand headlights with different and better performances in comparison with existing systems. Although a modern lighting system for motor vehicles would preferably fit numerous ambient conditions such as twilight, dawn, adverse weather (mist, rain, fog), and tunnels, it has to be noted that the highest demands are given to better illumination under bad weather conditions, in curves and at high speed on highway and motor-way.

In spite of the continuous improvement of both projection and reflection systems with either halogen or xenon gas discharge lamps, limitations still persist because the present systems are static, while night driving calls for a dynamic behaviour. The solution to the problem requires the definition of the most appropriate light distribution patterns and the switching strategy among the available light distributions.

## Adaptive Lighting Systems

The function "Adaptive front-lighting" is provided through system that tunes the beam pattern in relations to driving, weather and environment conditions. The main sub-functions are:

- *Bending:*

the purpose is to illuminate the curved lane to follow easier the trajectory;

- *High speed or motorway lighting:*

the purpose is to increase the visibility distance as a functionof the speed keeping glare at low level;

- *Country lighting:*

this beam pattern is mainly a low beam with a wider aperture angle which provides a good visilbility of the road edges;

- *Town driving*

a wide pattern is proposed to illuminate crossings, pedestrians and traffic signs;

- *Adverse weather lighting (wet road, mist and fog):*

in presence of fog or mist the beam is shaped to reduce backscattering,
on the wet road the beam is modifyed to reduce the glare caused by the direct reflection from the wet road;

- *Dawn, sunset, tunnel:*

automatic switching on is provided passing from daylight to low ambient illumination.

**Technical approaches**

There are several techniques and strategies to implement hardware solutions, but essentially they can grouped in two main categories:

- beams from several lamps added to a basic beam (ref. 1)
- movements of mechanical-optical parts to provide all the additional lighting functions (ref. 2).

The development strategy has been to generate novel front-lighting systems starting from the existing regulations and from the requests on bending and high speed functions.

Towards the implementation of all the above functions a lighting system with halogen lamps (Fig. 1) has been developed. It consists of sensors (speed, curve, external illumination intensity, presence of incoming vehicles, weather

conditions) linked to a dedicated microprocessor. This ECU drives the optical components via actuators and then offers all the functions described above (Fig.2a).

The system architecture is shown in figure 2b.

*Fig. 1 - Adaptive headlight demonstrator*

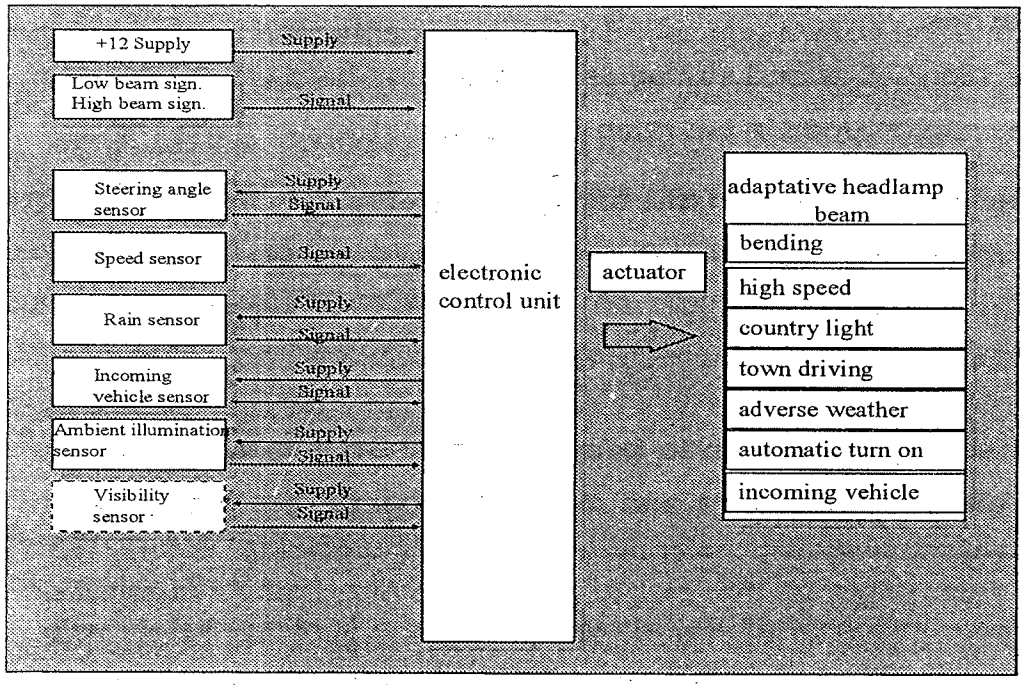


*Fig. 2a Adaptive Lighting System logic*

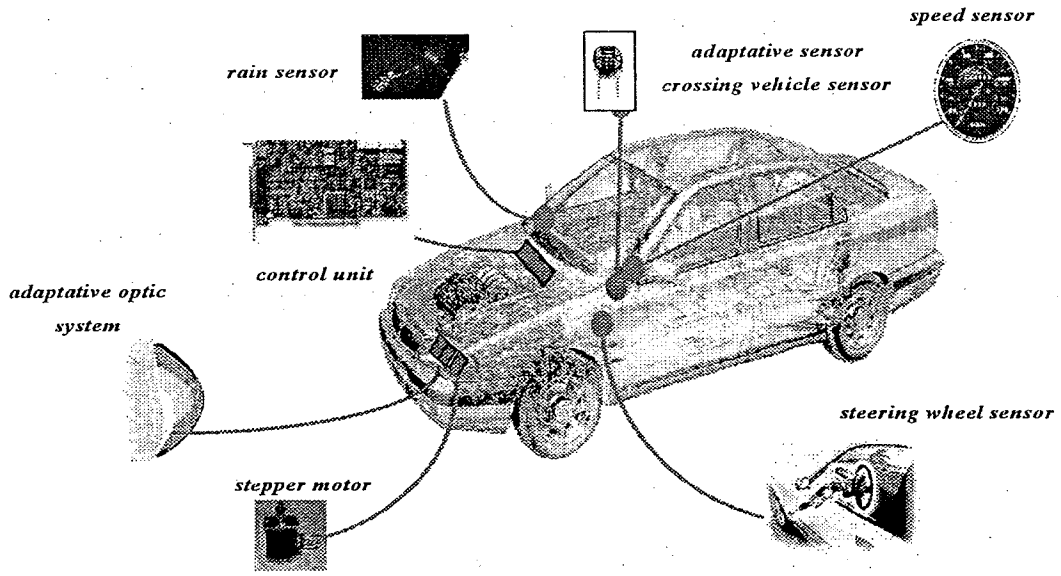


*Fig. 2b - System architecture*

Two arrays of lenses provide a continually adaptable beam that complements the main low beam. Relative movements of the two lens arrays shape the light distributions according to the SW strategy and the input conditions Specifically the transverse displacements of the arrays deflect the beam direction in relation to the steering angle, while the longitudinal displacements of them manage the beam divergence. Increasing the vehicle speed (Motorway beam) the additional light pattern gets narrower and improve the visibility distance. On the other hand a wide spread additional beam is obtained in an urban scenario.

**Road tests methodology for photometric specifications**

The eye contrast sensitivity measurement versus light beams characteristics has been carried out using a scientific methodology. The optical specifications for the new light beams have been set.

Figures 3a and 3b show driver's visual field mapping relative to the obstacles in visual scenario: lateral positions of signs, pedestrians, lane markings and generic obstacles on the lane for different distances (25, 40, 80, 120, 200

meters) are projected on the vertical screen at 25 meters from the driver. In these points were located, during field-tests in order to measure the contrast sensitivity of the driver-subject (figure 3c), calibrated visual stimuli with different values of sinusoidal luminous contrasts and pattern frequencies (Fig.3d). This methodology has based on the fact that for not so wide visual stimuli and near the visibility threshold, the human eye is a linear filter and any kind of visual stimulus can be broken up in a sum of visual stimuli with sinusoidal luminous contrast .

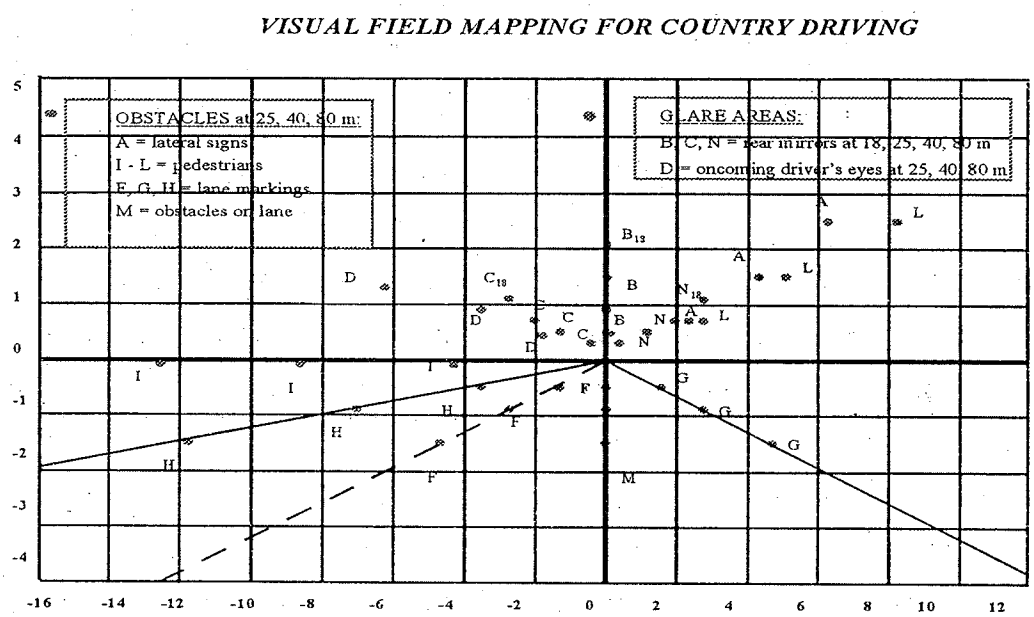


*Fig. 3a – Driver's visual field mapping during road tests in country driving conditions*

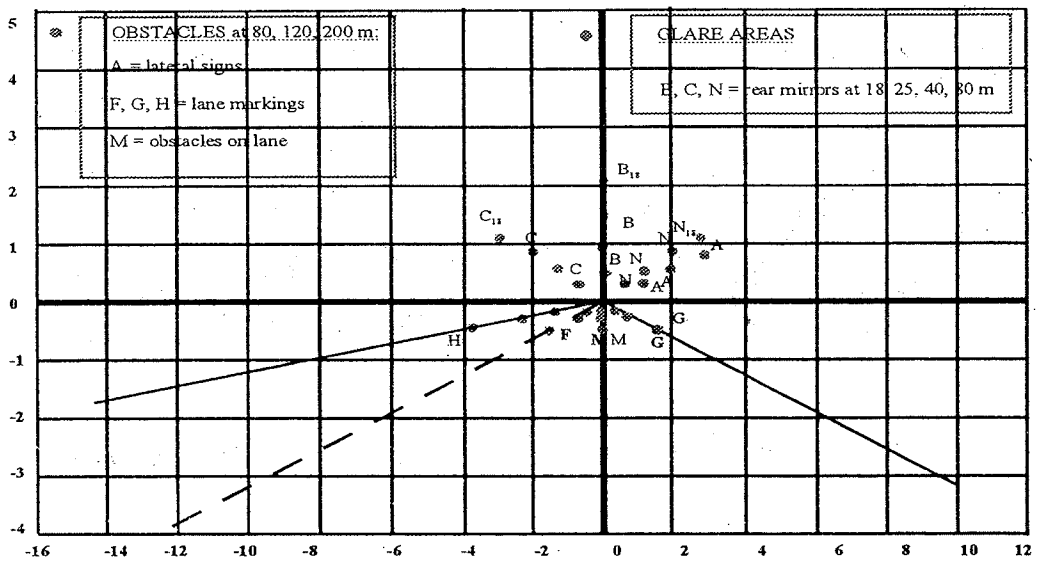


*Fig. 3b – Driver's visual field mapping during road tests in motorway driving conditions.*

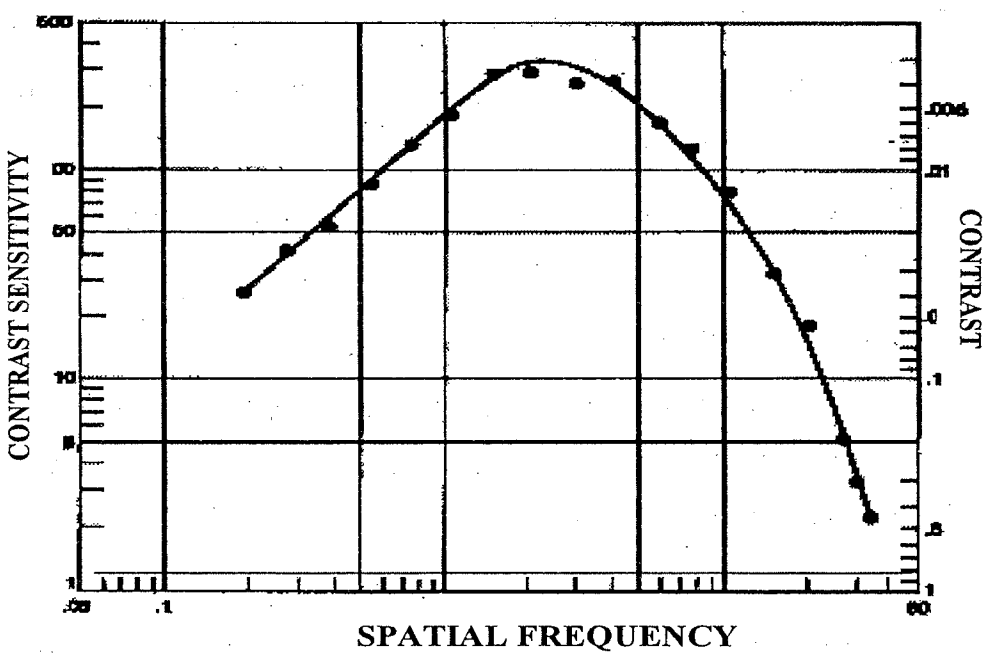


*Fig. 3c – Example of contrast sensitivity outputs obtained from road tests.*

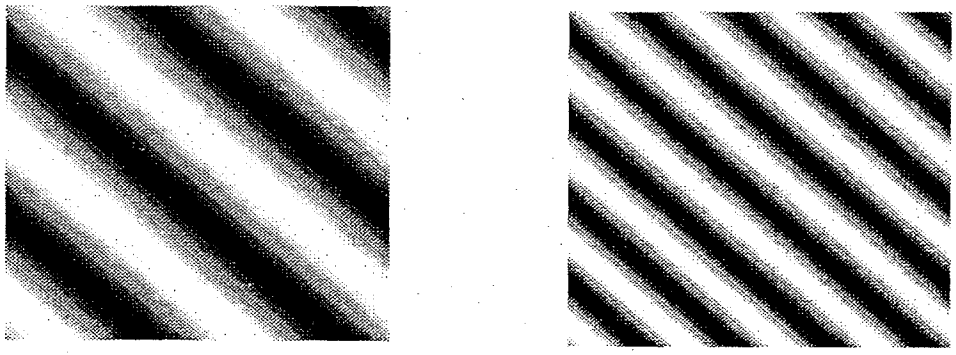

*Fig. 3d – Examples of calibrated visual stimuli used in road tests.*

The above methodology has been used for the road tests on a test car with headlamps prototypes. The optical specifications for the lighting functions of the adaptive lighting system have been defined.

Preliminary headlamps prototypes have been developed with lighting beams suitable for the different lighting functions (bending, motorway, country,...) with a high number degrees of freedom, this to achieve the desired light distribution.

The test car equipped with such a lighting system has been used to measure the visual sensitivity of the driver vs:

- distance and lateral position of the obstacles in the driver's visual field during driving task,
- light beams photometric characteristics.

Road tests results have been compared to the minimum value of contrast sensitivity requested during main driving task (lane keeping) and secondary driving task (signs, pedestrians, generic obstacles visibility). This value is a bit lower than 2.

At any fixed distance of the obstacles, the field tests have been carried out in three different conditions:

- without traffic conditions,

- with an oncoming car (in order to evaluate glare influence on oncoming driver's eyes),
- with an incoming car (to evaluate glare influence on rear view mirrors).

Measurements results in case of 40 meters distance for country driving conditions are shown in figure 3e. In this example we can see a good behaviour of headlamps prototypes, except in the right side of visual field where they are responsible for glare on right rear mirror.

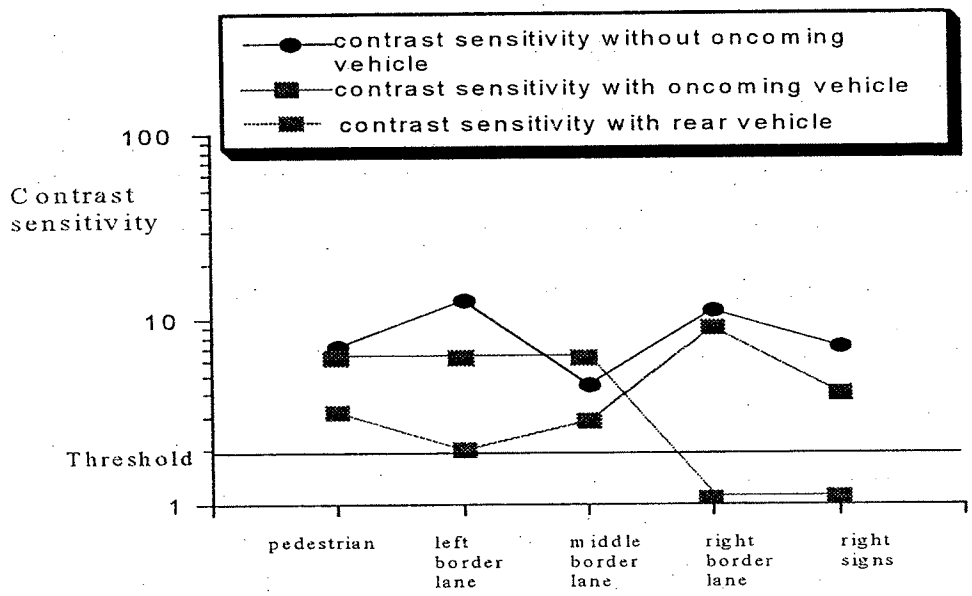


*Fig. 3e – Contrast sensitivity measurement results during CL driving situation in case of obstacles 40 meters far from the driver.*

From these results, photometric specifications of the different lighting functions of the adaptive system have been defined. Figures (4a, 4b, 4c, 4d) show some possible final pattern configurations of the additional beams for country light high speed, bending and town driving.

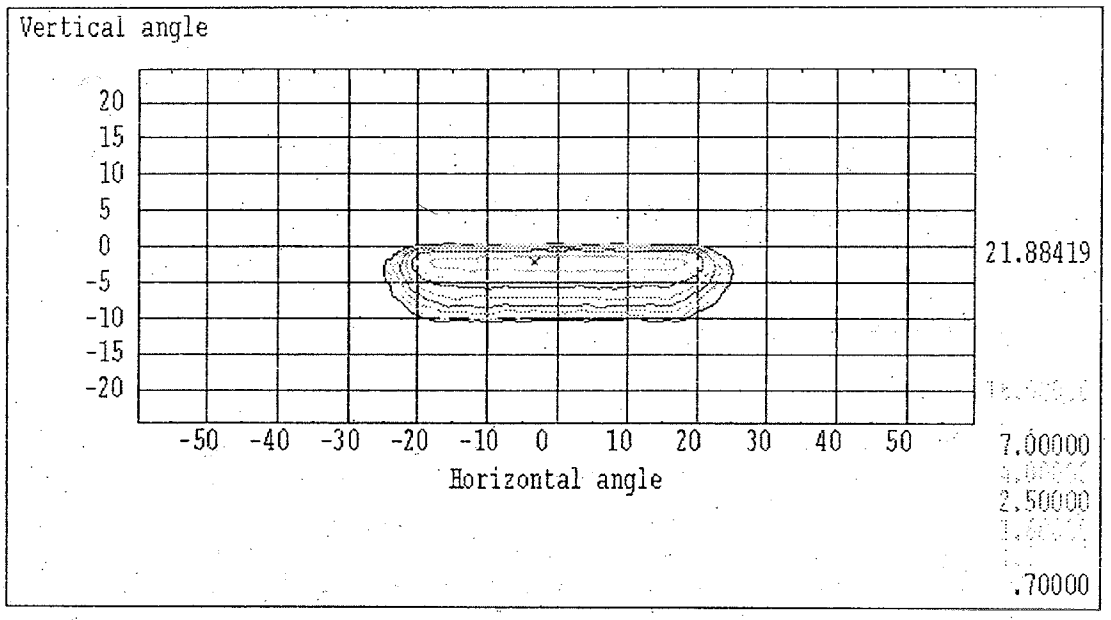


*Fig. 4a - Country beam*

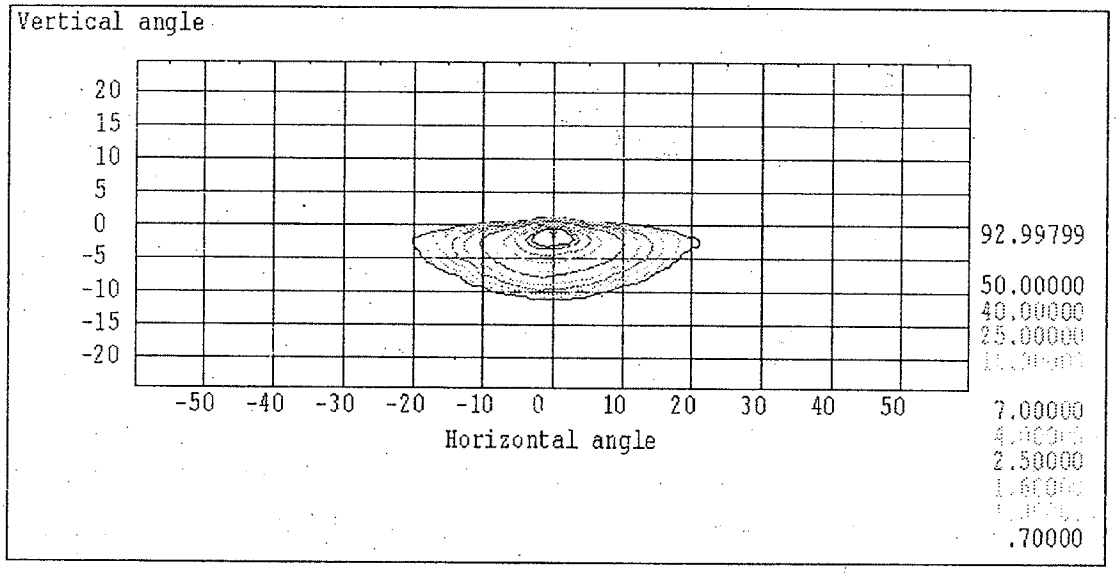


*Fig. 4b - High speed beam*

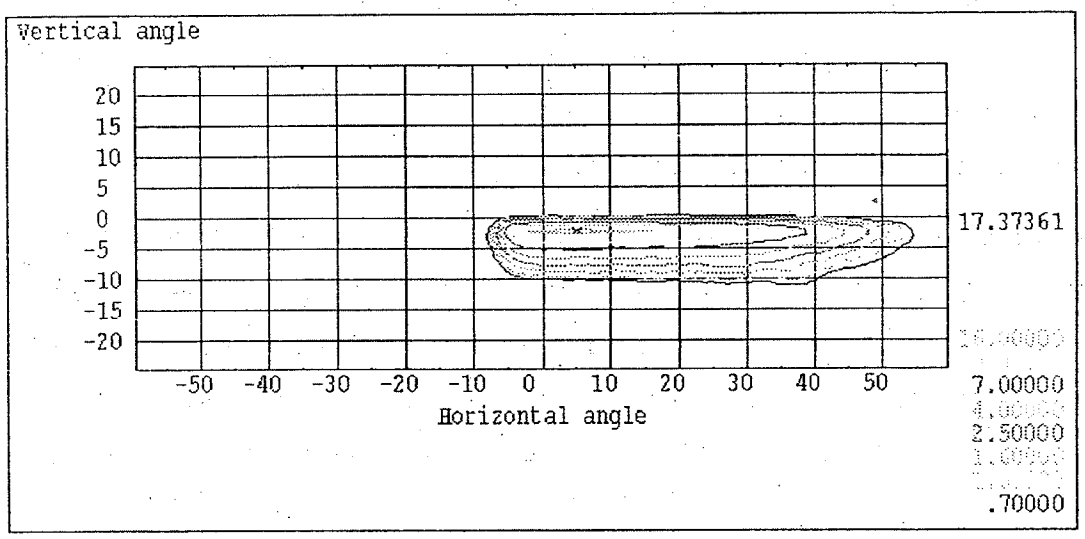


*Fig. 4c - Bending beam to the right*

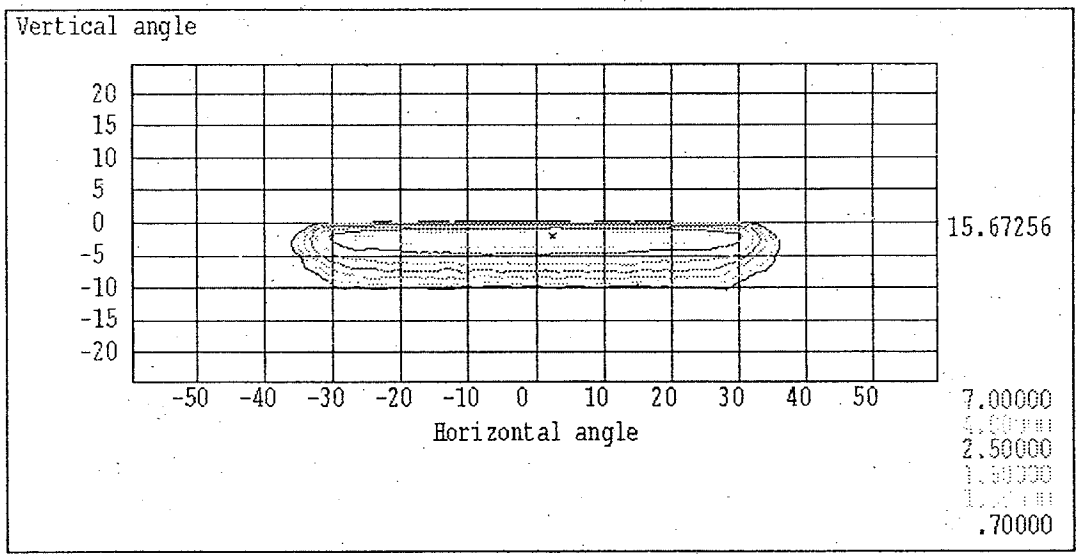


*Fig. 4d – Town beam*

**Control Strategies**

The implementation of an appropriated strategy to switch from one beam to another is a crucial issue. The trend to implement more and more electronics in the vehicle leads to the possibility to design real time controlled lighting systems having many input parameters for the control algorithm.
Dynamic levelling is an integral part of the headlamp system.

The switching among different lighting functions is controlled according to human eye capability to follow and to adapt itself to the dynamic of visual field illumination. In case of failure events during operation of the system recovery strategies are considered and implemented in the electronic control unit.
The advantages of the developed system respect to conventional ones are reported on table I:

*Tab I - ROAD ILLUMINATION REQUIREMENTS FOR AN ADAPTIVE LIGHTING SYSTEM*

| Devices | Beam patterns | Visibility on straight road | Visibility on curve (R150) | Illuminance requirement [lx] | Angular window for specified visibility |
|---|---|---|---|---|---|
| **Existing lighting systems** | Low beam | 58 m | 30 m | 40 | -- |
| | High beam | 140 m | -- | 120 | -- |
| **Adaptive headlight systems** | Country light | 80 m | -- | 20 | horiz.(-1°,1°); vert.(-0.75°,-0.3°) |
| | Bending beam | -- | 76 m | 6 | horiz.(-4°,35°); vert.(-1°,-0.5°) |
| | High speed beam | 200 m | -- | 3 | horiz.(-1°,1°); vert.(-0.3°,0°) |

## Future Developments

The definition of appropriated strategies for beam switching and control is far more the major issue on the evolution of intelligent lighting systems.

The introduction of data coming from accurate navigation systems comes as a first logical consequence. This predictive system would make possible to anticipate the needed light distribution avoiding dangerous changes in the beam during critical driving conditions such as curves and crossing. Other forms of refinement of the lighting strategies could be the dependence of the light pattern intensity distribution on data coming from stand alone sensorial systems (radar and infrared night vision) that could detect problems at a farther distance than that allowed by the headlamp. The optical and electronic solutions, for the new functions presented in this paper, are only examples of possible technical realisations and, hence, are no longer in the industrialised stage. Some efforts are still necessary before their introduction in the market especially for all functions together. A gradual or partial functions industrialisation is more affordable in the medium term.

A crucial aspect for the evolution of the front-lighting system scenario is the introduction of a new regulation comprising the definition of new rules and new specifications both for beam patterns and switching strategies.

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