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Automotive Adaptive Front Lighting Requiring Only On/Off Modulation of Multi-array LEDs

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The Adaptive Front-lighting System (AFS) is a part of the active safety system, providing optimized vision to the driver during night time and other poor-sight conditions of the road by automatic adaptation of lighting to environmental and traffic conditions. Basically, an AFS provides four different modes of the passing beam as designated in an United Nations Economic Commission for Europe regulation (ECE324-R123): neutral state or country light (Class C), urban light (Class V), highway light (Class E), and adverse weather light (Class W). In this paper, we first present an optics design for an AFS system capable of producing the Class C/V/E/W patterns requiring only on/off modulation of multi-array LEDs with no need for any additional mechanical components. The AFS optics consists of two separated modules, cutoff and spread; the cutoff module lights a narrow central area with high luminous intensity, satisfying the cutoff regulation, and the spread module forms a wide spread beam of low luminous intensity. Each module consists of two major parts; the first converts a discretely positioned LED array into a full-filled area emitting light source plane, and the second projects the light source plane to a 25 m away target plane. With the combination of these two optics modules, the four beam patterns are formed by simple on/off modulation of multi-array LEDs. Then we report the development of a prototype that was demonstrated to provide the four beam patterns.

Keywords : Adaptive front-lighting system, Headlamp, Low beam
OCIS codes : (080.2740) Geometric optical design; (120.4640) Optical instruments; (220.2945) Illumination design

I. INTRODUCTION

Headlamps have recently become intelligent, for driver convenience and safety [1-6]. These headlamps are called smart headlamps. Smart headlamps not only illuminate, but also vary the beam patterns according to weather conditions and driving situations. Examples include Adaptive Driving Beam (ADB) and Adaptive Front-lighting System (AFS). Adaptive Driving Beam (ADB), also called Glare-Free High Beam, varies high or driving beam patterns according to the location information of oncoming or preceding vehicles detected by a car camera [4, 7]. The AFS controls the aiming direction and lighting distribution of the low or passing beams according to driving and weather circumstances [8, 9]. Figure 1 shows beam pattern changes assisted by smart headlamps, which apply automatic soft switching between adaptive low and high beams.

With great advances of light emitting diode (LED) technology, LEDs have been applied successfully to exterior automotive lighting devices and also to headlights [10, 11]. Multiple LEDs, where individual LEDs can be automatically turned on/off, have been used in smart headlamps for modulating brightness and beam patterns [5, 8]. Very recently a high resolution LED light source was reported by a German research alliance [12]. The light source contains three LED light sources, each with 1,204 individually controllable light points. However, the high resolution LED sources are not yet in production and use.

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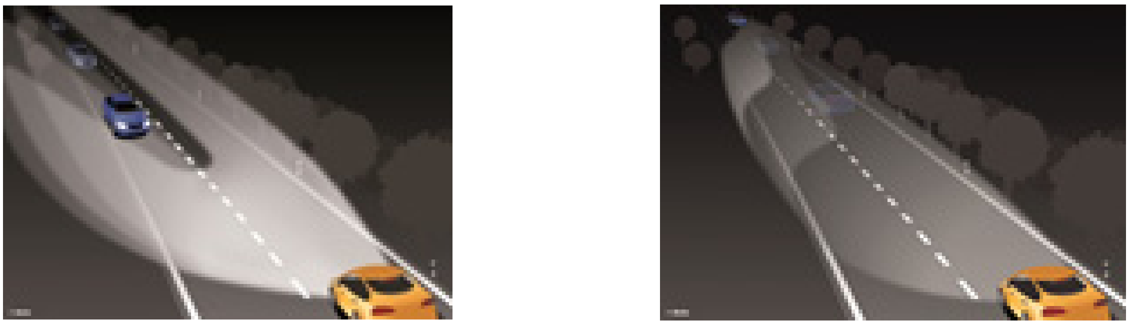


FIG. 1. Two possible beam pattern changes assisted by smart headlamps (Courtesy of HELLA, 2016). The drivers of oncoming and proceeding vehicles are not dazzled or blinded by the headlamp on high beam.

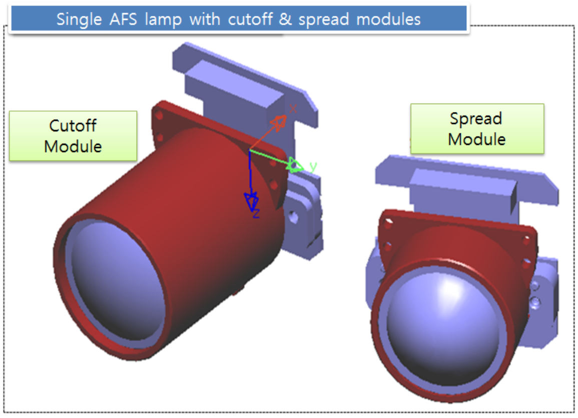


FIG. 2. 3D Model of an AFS lamp consisting of two separated modules (cutoff and spread).

This paper first presents an optics design capable of producing the AFS four beam patterns regulated by United Nations Economic Commission for Europe regulation (UN-ECE-R 123): neutral state or country light (Class C), urban light (Class V), highway light (Class E), and adverse weather light (Class W). The key idea behind the proposed system is the beam pattern is changed only through on/off modulation of multiple LEDs with no need for any additional mechanical components. Figure 2 show the 3D model of an AFS lamp consisting of two separated modules (cutoff and spread). In Section 3.0, we document the development of the prototype with photometric measurement results.

II. ADAPTIVE FRONT-LIGHTING OPTICS DESIGN

2.1. Definitions & Requirements

An AFS system is defined by a United Nations Economic Commission for Europe regulation (UNECE) as "a lighting device, providing beams with differing characteristics for automatic adaptation to varying conditions of use of the dipped-beam (passing beam) and, if it applies, the main-beam (driving-beam) with a minimum functional content; such systems consist of the "system control", one or more "supply and operating device(s)", if any, and the "installation units" of the right and of the left side of the vehicle" [9]. The AFS helps to improve visibility during nighttime driving by controlling the aiming direction and lighting distribution of the low beams according to ambient weather and visibility conditions, vehicle speed, and road curvature and contour.

Basically an AFS provides four different passing beam shapes: basic or country passing beam (Class C), urban passing (Class V), highway passing beam (Class E), and wet-road passing beam (Class W). An AFS also can provide a bending mode with its illumination being laterally moved or modified (to obtain an equivalent effect).

The basic/country passing beam (Class C) illuminates the right-hand edge of the road more brightly and widely than the conventional low beam in the case of right-hand traffic at speeds between 50 and 100 km/h. The urban passing beam (Class V) provides a wider light distribution at a reduced speed range below 50 km/h, helping drivers to more clearly see pedestrians on the edge of the road. The highway passing beam (Class E) illuminates the road-way significantly further ahead and focuses more on the left-hand edge of the road. The motorway light switches on automatically at speeds greater than 100 km/h. The

Class	Functions	Beam patterns
C	Basic or country passing beam	
V	Urban passing	
E	Highway passing beam	
W	Wet-road passing beam	

FIG. 3. Basic AFS beam patterns (Class C/V/E/W).

TABLE 1. AFS passing-beam photometric requirements expressed in candela. Reference angular positions and lines are expressed in degree and marked in Fig. 4

No	Elements (position/line)	Position (deg)		Class C		Class V		Class E		Class W	
		Horizontal	Vertical	Min	Max	Min	Max	Min	Max	Min	Max
1	B50L	L 3.43	U 0.57	50	350	50	350	50	625	50	625
2	HV	V	H	50	625	50	625	50		50	
3	BR	R 2.5	U 1.0	50	1,750	50	880	50	1,750	50	2,650
4	Segment BRR	R 8~20	U 0.57	50	3,550		880		3,550		5,300
5	Segment BLL	L 8~20	U 0.57	50	625		880		880		880
6	P	L 7	H	63						63	
7	S50 + S50LL + S50RR		U 4	190				190		190	
8	S100 + S100LL + S100RR		U 2	375				375		375	
9	50R	R 1.72	D 0.86			5,100					
10	75R	R 1.15	D 0.57	10,100				15,200		20,300	
11	50V	V	D 0.86	5,100		5,100		10,100		10,100	
12	25LL	L 16	D 1.72	1,180		845		1,180		3,400	
13	25RR	R 11	D 1.72	1,180		845		1,180		3,400	
14	Segment 20 and below it	L 3.5 ~ V	D 2								17,600
15	Segment 10 and below it	L 4.5 ~ R 2	D 4		12,300		12,300		12,300		7,100
16	Emax			16,900	44,100	8,400	44,100	16,900	79,300	29,530	70,500

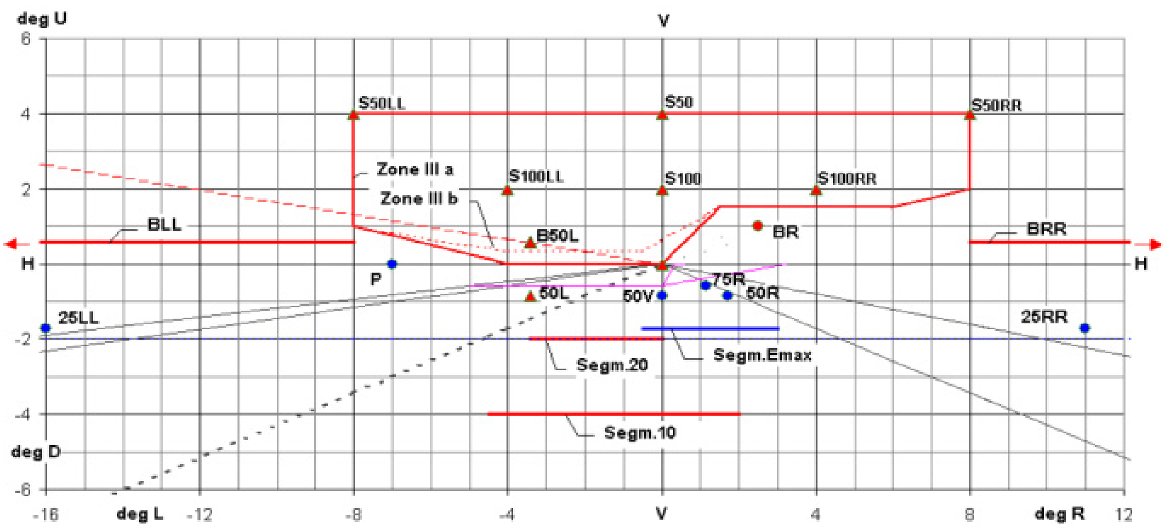


FIG. 4. Reference angular positions and lines used in AFS passing-beam photometric requirements (indicated for right-hand traffic). Angular positions are expressed in degree up (U) or down (D) from H-H respectively right (R) or left (L) from V-V [9].

wet-road passing beam (Class W) more strongly illuminates the edges of the road for better orientation to the guiding lines. Figure 3 shows the four beam patterns of Class C, V, E, and W. Detailed photometric requirements on each beam are regulated in annex 3 of the UNECE regulation, ECE324-R123 [9]. Table 1 lists major photometric requirements at the reference angular points or lines, as indicated in Fig. 4.

2.2. Optics Design: Two Module Approach

AFS optics should achieve the aforementioned performance level in terms of luminous flux, peak intensities, distribution characteristics, homogeneity, and other attributes, as noted in Section 2.1. An AFS system with a high-intensity discharge (HID) bulb creates several light distributions via ballast and motor/shutter control.

This study selects LEDs as the AFS light source because of their fast reaction time, energy-savings, and very long lifetimes. In order to utilize the full functionality of LEDs, we propose an AFS optics concept capable of producing the Class C/V/E/W patterns requiring only on/off modulation of multi-array LEDs with no need for any additional mechanical components. The AFS consists of two separated modules (cutoff and spread), as in Fig. 2; the cutoff module lights a narrow central area with high luminous intensity satisfying the cutoff regulation, and the spread module forms a wide spread beam of low luminous intensity. Each module switches on/off and ballasts LEDs to form the four class beam patterns. The concept of beam combination from left-hand side and right-hand side AFS lamps is illustrated in Fig. 5.

The cutoff module is designed to light a narrow central area with high luminous intensity satisfying the cutoff regulation. In particular the cutoff module should switch on/off the specific (or localized) portion of the central area for generating the wet road passing beam (Class W) as shown in Fig. 3. The cutoff module consists of multi-array LEDs, a micro-lens array, a cutoff shield, and a projection lens as shown in Fig. 6(a). A similar construction was previously applied in an adaptive dynamic beam (ADB) [8]. The micro-lens array first converts a discretely positioned LED array into a full-filled area emitting light source plane, as shown in Fig. 7, at the focal plane of the projection lens. The projection lens conjugates this plane

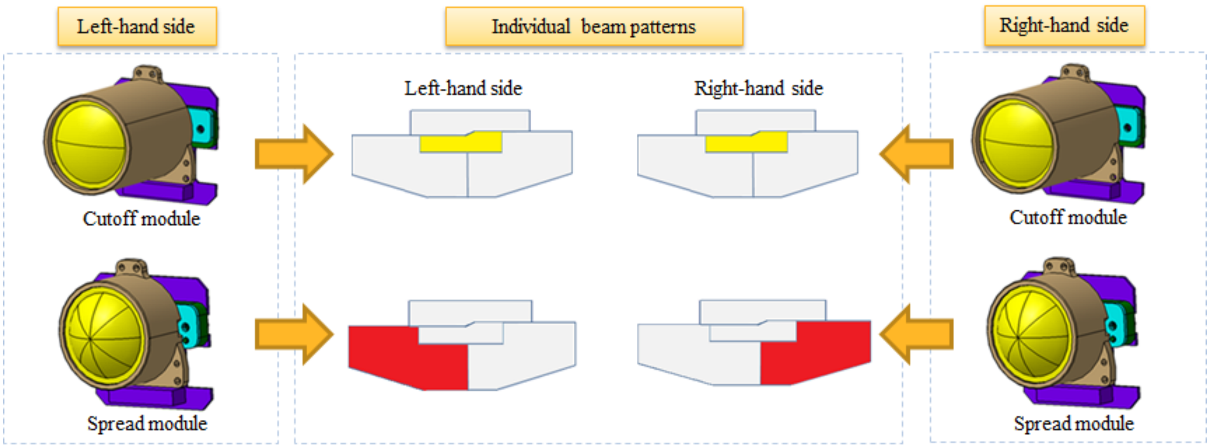


FIG. 5. Beam combination by left-hand side and right-hand side AFS lamps.

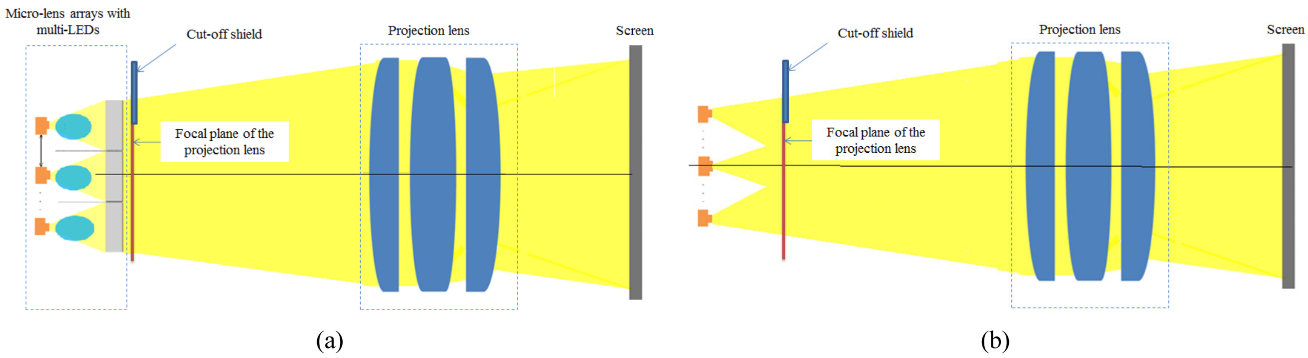


FIG. 6. Optical concept of the cutoff & spread modules. (a) Cutoff module, (b) Spread module.

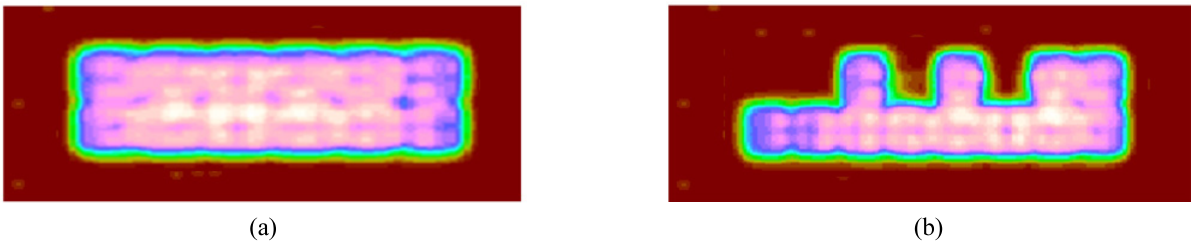
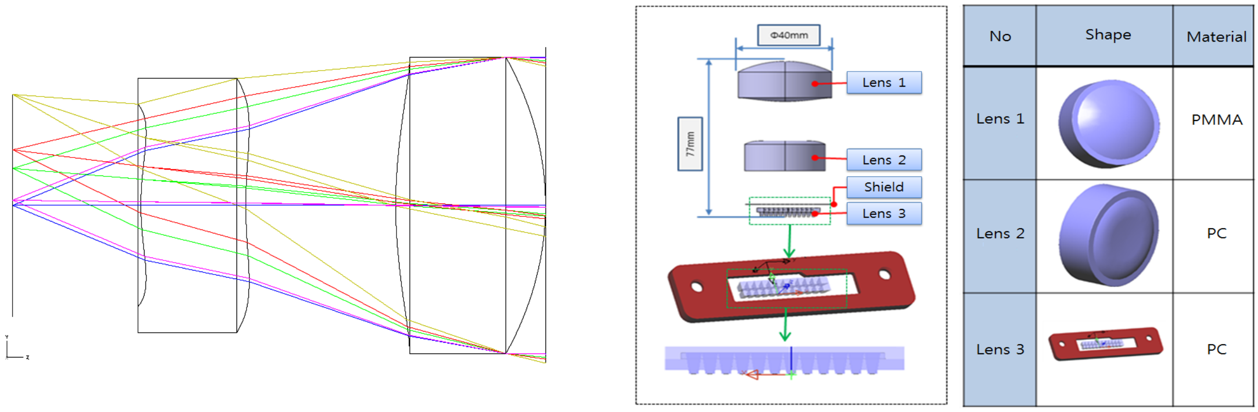
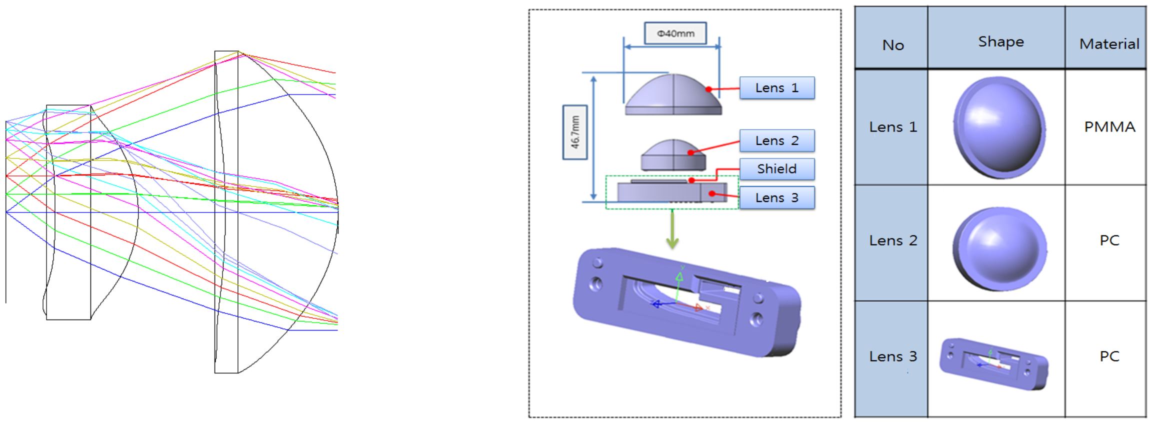


FIG. 7. Irradiance at the focal plane of the projection lens formed by the micro-lens array with discretely positioned multi-LEDs. (a) When all LEDs are on, (b) When some LEDs are off.



(a) (b)

FIG. 8. Optical construction of the cutoff module. (a) Optical layout of the projection lens, (b) Optical composition.



(a) (b)

FIG. 9. Optical construction of the spread module. (a) Optical layout of the projection lens, (b) Optical composition.

(a) (b)

FIG. 10. Simulated Class C and W beam patterns formed by the right AFS system at a screen situated 25 m away. (a) Class C pattern, (b) Class W pattern.

cut-off by the cut-off line shield onto a target plane located 25 m away with a focal length of 50 mm. The spread module similarly consists of multi-array LEDs, a shield, and a projection lens but without the micro-lens array as shown in Fig. 6(b). The spread module forms a wider spread beam of low luminous intensity with a projection lens of 22 mm focal length. Figures 8 and 9 show the optical layout and optical composition of the cutoff and spread modules, respectively. Figure 10 shows the simulated class C and W beam patterns formed by the right AFS lamp at a screen located 25 m away.

III. PROTOTYPE DEVELOPMENT

Two sets of the prototype were developed, for left and right AFS lamps. Figure 11 shows the prototype of the

FIG. 11. Prototype of the AFS optics consisting of two beam modules (cutoff and spread).

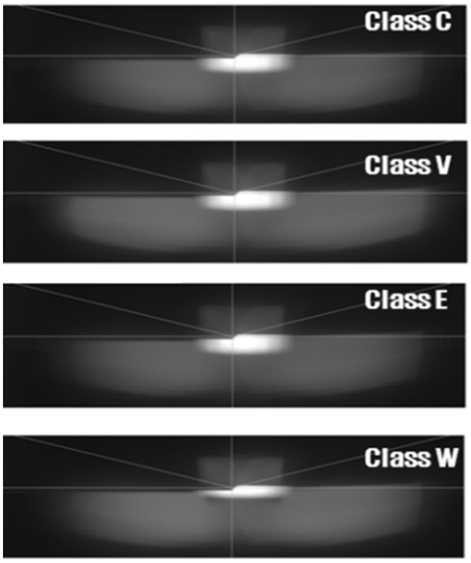


FIG. 12. Four beam patterns (Class C/V/E/W) formed by the left and right AFS systems together at a screen situated 25 m away.

AFS optics consisting of two beam modules (cutoff and spread). The left and right modules in the picture are the cutoff and spread, respectively.

Figure 12 shows the measured beam patterns formed by the left and right AFS lamps together at a screen located 25 m away, which were in good accordance with the simulated prediction as shown in Fig. 10. The test confirmed our AFS provides the four beam patterns (Class C/V/E/W) regulated in ECE324-R123 [9]. As an example, Table 2 lists the photometric measurement results of Class V and their compliance to the regulation. Figure 13 shows pictures of the four beams on the road at night, which were taken at an internal test facility of SL Lighting Corporation. The significant variances from the basic passing beam (Class C) are box-dotted in each picture.

IV. CONCLUSION

Smart headlamps such as AFS have recently been developed for improved safety, convenience, and driver performance. LEDs are now being applied in various smart headlamps after their successful application to exterior automotive lighting devices and conventional headlights. We presented an AFS system consisting of two beam modules called cutoff and spread modules. By performing a computer simulation and then developing a prototype, our optics design was demonstrated to provide four beam patterns (class C/V/E/W), achieving the stipulated performance levels in terms of luminous flux, peak intensities, distribution characteristics, homogeneity and other attributes as regulated in ECE324-R123.

TABLE 2. Photometric measurement results of Class V of the AFS system and their compliance to ECE324-R123

No	Elements (position/line)	Position (deg)		Requirement		Measurement	Compliance
		Horizontal	Vertical	Min	Max		
1	B50L	L 3.43	U 0.57	50	350	310	Yes
2	HV	V	H	50	625	610	Yes
3	BR	R 2.5	U 1.0	50	880	725	Yes
4	Segment BRR	R 8~20	U 0.57		880	534	Yes
5	Segment BLL	L 8~20	U 0.57		880	151	Yes
9	50R	R 1.72	D 0.86	5100		24,051	Yes
11	50V	V	D 0.86	5100		18,163	Yes
12	25LL	L 16	D 1.72	845		1,106	Yes
13	25RR	R 11	D 1.72	845		9,768	Yes
15	Segment 10 and below it	L 4.5 ~ R 2	D 4		12,300	10,081	Yes
16	Emax			8400	44,100	24,928	Yes

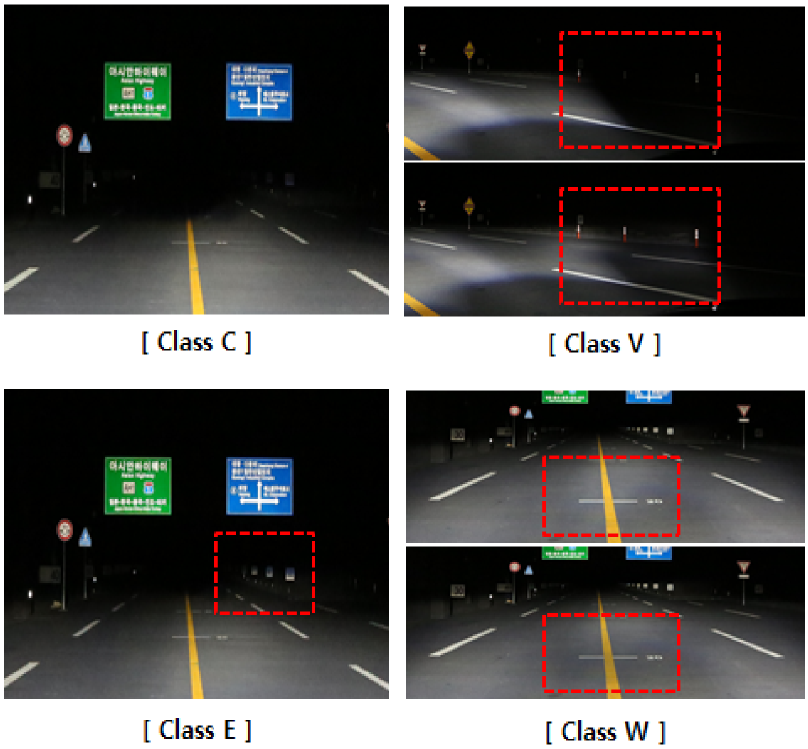


FIG. 13. Four beam patterns formed by the left and right AFS systems together at a screen located 25 m away. The measurement was performed at an internal test facility of SL Lighting Corporation.

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