THE USE OF LED LAMPS FOR TURN AND STOP SIGNAL PRESENTATIONS

Paul L. Olson, Toshiaki Aoki, and Dennis S. Battle

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109

Report No. UMTRI-89-35
December, 1989

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-89-35		

4. Title and Subtitle	5. Report Date
THE USE OF LED LAMPS FOR TURN AND STOP SIGNAL PRESENTATIONS	December, 1989
	6. Performing Organization Code: 302547
7. Author(s): Paul L. Olson, Toshiaki Aoki, and Dennis Battle	8. Performing Organization Report No.: UMTRI-89-35
9. Performing Organization Name and Address: The University of Michigan Transportation Research Institute Ann Arbor, Michigan 48109-2150 U.S.A.	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: Stanley Electric Co., Ltd. 2-9-13 Nakameguro, Meguro-ku Tokyo 153, Japan	13. Type of Report and Period Covered: Final
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

LEDs have been developed that are suitable for use in automotive signal lamps. As signal light sources, LEDs have a number of advantages, among which are faster rise times, long life, flexibility in lamp size and shape, and the possibility of unique modes of presentation that may improve signal performance. The purpose of the research described in this paper was to examine driver preferences and response time to unique stop and turn signal presentations using LED sources. The results suggest that subjects preferred some of the signal modes to present-day configurations, and responded faster to them under a variety of conditions.

17. Key Words	18. Distribution Statement
LED, rear lighting, turn signals, brake signals	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	18	

ACKNOWLEDGEMENT

This work was carried out with funding from Stanley Electric Company, Ltd. of Tokyo, Japan. Their support of and interest in the UMTRI research program is gratefully acknowledged.

CONTENTS

LIST OF TABLES

INTRODUCTION

The use of light-emitting diodes (LEDs) for marking and signaling lamps on motor vehicles became possible with the recent development of high-intensity LEDs. The use of LEDs rather than conventional bulbs for vehicle lighting has certain advantages. Among these are the fact that the LED, not having a filament, is a very long-lasting source. In addition, since an LED lamp is made up of a large number of individual sources, it can be made in a variety of shapes to fit different applications or styling needs and still present a uniform appearance.

A more important advantage of the LED may lie in its operating characteristics. LEDs reach peak intensity in nanoseconds, while a filament bulb of the type used in rear signaling devices will typically require 0.15 to 0.20 second. This means that an LED lamp will provide additional warning time of a brake application to following drivers. This gain was found to range from 0.2 to 0.3 second on average, depending on conditions, in one investigation (Olson, 1987).

LED lamps also make possible certain types of signal presentations that may be useful. For example, because of their very rapid rise and decay time, it is possible to flash an LED source at a much higher rate than a conventional lamp. High flash rates should have good attention-getting value, and, if they are different enough from the flash rates presently used for turn and emergency signal applications to be reliably distinguished, offer another coding dimension that may be helpful in identifying certain potentially dangerous situations (such as hard braking). Another type of presentation comes from the fact that an LED lamp is composed of a number of individual sources. It is possible to energize these sources in such a way as to create useful or interesting patterns. For example, a turn signal could be presented by having the light sweep across the lamp face in the desired direction. While this may be viewed primarily as a novelty, it may prove to be a superior means of indicating a turn, particularly under conditions where both sides of the car cannot be seen.

The purpose of the study to be described in this paper was to explore the two possibilities just described. It was a two-part investigation. Part one was a subjective analysis of various modes of stop and turn signal presentation, intended to assess the preferences of the subjects and their opinions concerning signal effectiveness compared with conventional modes of presentation. Part two was an objective study in which measures were made of subject response time to the signal presentations under various conditions.

METHOD

Three test lighting units were made available for the study. Two of these used LEDs, and were a matched pair, i.e., one for the right and one for the left side of the car. The third used two conventional tungsten bulbs, and was designed for the left side of the car. Each unit was 60 cm long and 12 cm high. Each LED unit consisted of 56 columns of 9 LEDs, with each LED being about 1 cm in diameter. The units were made to conform to current rear lighting specifications, and were matched photometrically. Photometric data on these three units are provided in the Appendix.

The LED units were programmed to provide four different types of turn signals. Each of these signals could be varied in terms of cycle time and the number of columns of LEDs simultaneously actuated. The units were also programmed to provide brake signals, which could be preceded by brief flashes. These could be varied in terms of the number of flashes and the cycle time of each.

The four turn signal systems are illustrated in Figure 1. In System 1 the signal started in the off condition, and successive columns of LEDs were illuminated, sweeping in the desired direction. System 2 worked in the opposite mode, starting fully lighted, with successive columns of LEDs being extinguished, sweeping in the desired direction. System 3 was fully lighted, with a dark area sweeping across in the desired direction. System 4 started in the off condition, then showed light and dark areas sweeping in the desired direction. Cycle time for the turn signals could be varied from 20 to 150 cycles/minute. The size of the lighted or unlighted section could be 1, 3, 6, or 9 columns of LEDs.

The number of flashes preceding the brake signal could be varied from 0 to 9. The flash rate could be varied from 60 to 600 flashes/minute.

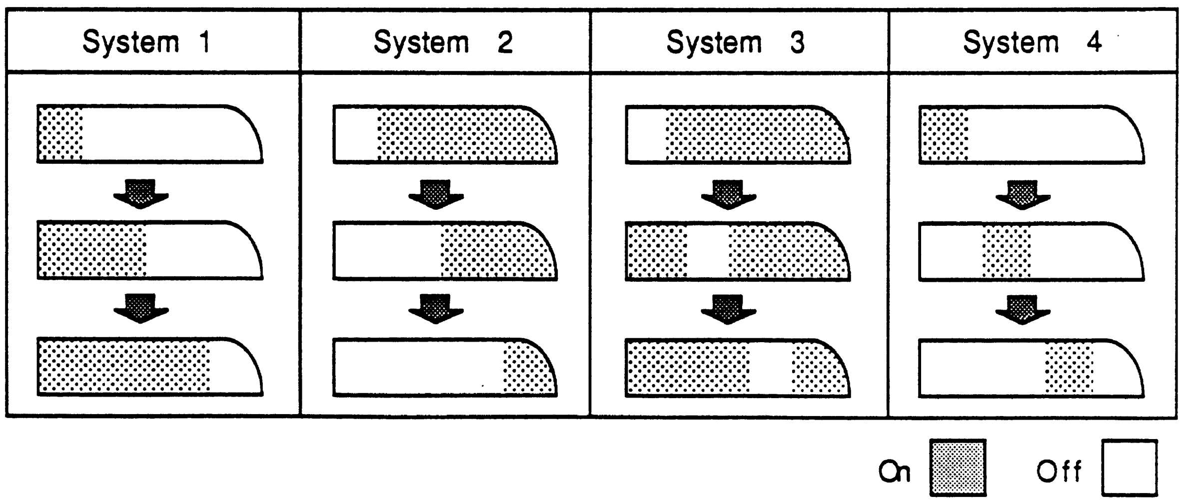

Figure 1. Illustration of operating modes of four LED turn signal systems.

SUBJECTIVE EVALUATION

Procedure. The purpose of this study was to obtain ratings of the various stop and turn signal combinations made possible by the equipment relative to conventional stop and turn signals. Subjects observed the displays on the rear of one vehicle at a distance of about 60 m while seated in another vehicle. The subjects were asked to evaluate the systems relative to conventional brake-turn displays with which the subjects were familiar through their personal driving experience. Ratings were made using a five-point scale as follows:

1. Much better than present systems
2. Better than present systems
3. About the same as present systems
4. Worse than present systems
5. Much worse than present systems

The signal equipment was attached to a board, which was painted black and mounted on the rear of a station wagon in such a way that the standard rear lighting was covered. All of the equipment for controlling the signals was contained within the station wagon.

The turn signals viewed by the subjects included all four systems, five rates (150, 100, 80, 50, and 30 cycles/minute) and three sizes of the lighted or unlighted section (1, 2, and 4 columns of LEDs). Systems 1 and 2 were evaluated only with section sizes 1 and 4. Preliminary analysis indicated that Systems 3 and 4 did not appear effective with a section size of 1, so they were evaluated at section sizes 2 and 4. System 3 also did not appear effective at the higher rates, so it was evaluated only at the three lower rates.

The flashing stop signals were viewed by the subjects at five flash levels (1, 3, 5, 7, and 9 flashes preceding the steady on) at the highest flash rate, and at four rates (600, 300, 200, and 150 flashes/minute) for seven flashes.

Subjects were run in groups of three. All were seated in the front of one vehicle, facing the rear of the vehicle on which the test lamps were mounted. In the instructions they were told that they would see a number of presentations of stop and turn signals, all of which would be different in some respect from signals they were used to seeing. They were to rate these signals, using the scale described above. In the case of the brake presentations, they were also told that the signal would start with a series of brief flashes, which might be useful to indicate special situations such as emergency braking. Examples of each form of presentation were shown. When instructions had been completed, questions were answered and presentations began.

In the daytime test two complete sets of ratings were taken, one with the car having the test lamps on it facing north, so that the sunlight impinged directly on the lamp surfaces, the other with it facing south. At night only one set of ratings was taken.

Results. The results of the daytime north- and south-facing turn-signal evaluations were found to be essentially the same, so are combined in Table 1. Bearing in mind that ratings of less than 3 indicate an evaluation as better than present systems, an inspection of Table 1 makes it clear that the subjects rated System 3 no better than present systems under any condition. They rated System 4 slightly better than present systems under one condition (80 cycles/minute) at section size 2, and two conditions (100 and 80 cycles/minute) at section size 4. Systems 1 and 2 fared better in the ratings, but the preferences are clearly dependent on the rate. Rates of 80 to 100 cycles/minute were associated with the most favorable ratings.

The results of the nighttime evaluations are given in Table 2. The trends are much the same as noted in the daytime evaluations. All data are combined in Table 3. It is clear from these data that Systems 1 and 2, at rates of 80 and 100 cycles/minute, are the most promising from the point of view of driver preference.

TABLE 1. Mean Ratings of Turn Signals Under Daytime Conditions

Flashes / Minute	System 1	System 2	System 3	System 4
150	2.75	2.89		3.21
100	2.50	2.46		3.00
80	2.32	2.75	3.93	2.82
50	3.21	3.54	3.89	3.18
30	4.14	4.29	4.21	3.89
	Area = 1		Area =2	

Flashes / Minute	System 1	System 2	System 3	System 4
150	2.64	2.93	3.64	3.25
100	2.29	2.68	3.21	2.64
80	2.14	2.64	3.18	2.86
50	3.14	3.11	3.79	3.11
30	3.68	3.93	4.00	3.64
	Area = 4			

TABLE 2. Mean Ratings of Turn Signals Under Nighttime Conditions

Flashes / Minute	System 1	System 2	System 3	System 4
150	2.70	2.57		2.63
100	2.30	2.67		2.30
80	2.10	2.67	4.37	2.40
50	2.57	3.13	4.20	3.33
30	3.47	3.50	4.47	3.60
	Area = 1		Area =2	

Flashes / Minute	System 1	System 2	System 3	System 4
150	2.63	2.63	3.83	2.70
100	2.43	2.63	3.80	2.77
80	2.20	2.67	3.40	3.50
50	2.73	3.10	3.97	3.80
30	3.10	3.07	3.97	3.80
	Area = 4			

TABLE 3. Mean Ratings of Turn Signals Under Both Daytime and Nighttime Conditions

Flashes / Minute	System 1	System 2	System 3	System 4
150	2.73	2.78		3.02
100	2.43	2.53		2.77
80	2.25	2.72	4.07	2.68
50	3.00	3.40	4.00	3.23
30	3.92	4.02	4.30	3.80
	Area = 1		Area =2	

Flashes / Minute	System 1	System 2	System 3	System 4
150	2.64	2.83	3.71	3.07
100	2.33	2.66	3.41	2.68
80	2.16	2.65	3.25	3.07
50	3.01	3.10	3.85	3.34
30	3.49	3.64	3.99	3.70
	Area = 4			

The evaluations of the brake presentations are given in Table 4. On the left side of the table is shown the mean ratings for a fixed number of flashes (7) and various rates. On the right is shown the mean ratings for a fixed rate (600 flashes/minute) and different numbers of flashes. It is apparent that the subjects generally rated the flashing brake light as about equal to present braking systems. To the extent that there are differences, they favor 5 to 7 flashes total and the higher rates.

TABLE 4. Mean Ratings of Stop Signals Under Various Conditions

Ambient Lighting	Direction	Flashes / Minute 600	300	200	150	Number of Flashes 1	3	5	7	9
Daytime	South	2.71	2.71	3.36	3.21	3.29	2.79	2.64	2.57	2.86
	North	2.71	2.93	3.21	3.36	3.29	3.07	3.00	3.00	2.93
Nighttime		2.83	3.00	2.83	3.25	3.00	3.08	3.08	3.08	3.42
Average		2.75	2.88	3.13	3.27	3.19	2.98	2.91	2.88	3.07

REACTION TIME STUDY

Procedure. The purpose of this study was to assess the attention-getting properties of the different signal presentation modes. The physical arrangement was much the same as in the subjective study, in that subjects were seated in one vehicle and observed signals presented by the test units mounted on the rear of another vehicle located about 75m in front of them. The main difference was that subjects pressed a button when they had detected and identified the signal rather than making a rating.

Not all of the signals evaluated in the subjective study were used in this phase. In the case of turn signals, only Systems 1 and 2 were used, as these were the ones most often rated better than present systems. The size of the lighted section was kept to 1 column of LEDs for the same reason. Three rates were employed, 150, 100, and 60 cycles/minute. This made a total of six LED turn signals. In addition, the conventional incandescent unit was utilized, at 86 cycles/minute.

In the case of brake signals, six flashing signals were presented. These were made up of three rates (600, 300, 200 flashes/minute) and two flash counts (3 and 7). In addition, a "conventional" signal was presented (using the LED units) in which the units came on at full intensity without flashing.

The study was run both day and night. The arrangement of the equipment and the subject instructions were the same in each case, the only physical difference was that at night the lamps were illuminated continuously at presence level (see photometric tables). Due to restrictions imposed by the equipment, the incandescent turn signal was not used at night.

Subjects were run individually. Each reported to the Institute and was seated in the test car. Instructions were read to them. They were told that their job was to detect the signals, identify them as brake or turn signals, and, in the case of turn signals, identify which direction was being indicated. They should then press the button provided. There was no way to verify that the subjects actually carried out all the processing requested, so the results can be interpreted as representing only detection. The subjects were also told that they must not look directly at the lamp display. Instead they were told to look at a street lamp located in the distance, and about four degrees above the top of the car with the lighting display. Thus, detection was peripheral.

A total of ten subjects participated in the study under both ambient conditions. Only two subjects participated in both sessions. All were licensed drivers. Ages ranged from about 25 to 70 years. Representation of the sexes was equal.

Results. The results for brake signals are given in Table 5. The table lists the mean response time measured for each condition. Statistical tests were run, with a significance level of 0.05 being the minimum acceptable. At night the mean response times for the flashing stop lamps ranged from 0.53 to 0.56 second. These values do not differ significantly. All were somewhat faster on average than the conventional presentation (0.58 second), although the difference is short of statistical significance.

A very similar picture is evident for the daytime data. Once again, the times for the flashing brake lamps do not differ significantly. However, the time for the fastest flashing stop lamp (0.51 second) does differ significantly from that for the conventional stop lamp (0.60 second) at the 0.01 level, and the times for the other flashing stop lamps (with the exception of the one with a mean of 0.57 second) differ from the conventional stop lamp at the 0.05 level.

Table 6 gives the mean response times to the various turn signal presentations. Of the LED systems, during the day, only the System 1, slow-rate presentation differed significantly from the other five (0.05 level). All, however, were significantly faster than the conventional turn signal (0.01 level). At night, the fastest of the System 1 signals and all of the System 2 signals did not differ statistically. The two slower System 1 signals had significantly longer response times than the fastest System 1 signal (0.05 level).

TABLE 5. Mean Response Times to Brake Signals as a Function of Various Test Conditions

Flashes / Minute	Daytime: Number of Flashes 3	Daytime: 7	Daytime: 0	Nighttime: Number of Flashes 3	Nighttime: 7	Nighttime: 0
600	0.53	0.57		0.54	0.53	
300	0.53	0.51		0.54	0.53	
200	0.54	0.53		0.56	0.54	
just on			0.60			0.58

TABLE 6. Mean Response Times to Turn Signals as a Function of Various Test Conditions

Flashes / Minute	Daytime: System 1	Daytime: System 2	Daytime: Conv	Nighttime: System 1	Nighttime: System 2
150	0.51	0.51		0.56	0.55
100	0.52	0.51		0.63	0.51
60	0.64	0.52		0.68	0.59
86			1.06		

DISCUSSION

The results of this investigation suggest that the use of LED signal lamps on motor vehicles may convey safety advantages beyond those envisioned in earlier work (e.g., Olson, 1987). In this study two possibilities for the use of such lamps were explored. One was their use to provide additional warning in brake lamps. For example, causing the brake lamps to flash at a high rate for a short period of time might prove a useful signal for an unusual, high-hazard action such as hard braking. Flashing lamps have good attention-getting value, and there might be merit in providing a special signal for certain hazardous conditions. Even though this study was conducted under circumstances where the subject could focus maximum attention on the task at hand, the results suggest that the flashing lamps improved subject response time compared to the traditional display. The potential of LEDs for a display of this type seems worthy of further investigation.

The results of the turn signal evaluation were particularly interesting. Both day and night the best of the LED turn signals elicited mean response times between 0.50 and 0.55 second. The mean response time for the turn signal with incandescent bulbs was 1.06 second. Other work (Olson, 1987) that compared subject response time to signals with both types of light sources found an advantage for the LEDs that ranged from 0.2 to about 0.3 second, apparently associated with the difference in rise-time characteristics. If we take the largest of these numbers (0.3 second) and subtract it from the mean time obtained for the conventional turn signal in this test, the corrected time is 0.76 second, still longer than the times associated with any of the LED signals evaluated, and about half again as long as the best of them. This suggests that the unique turn displays made possible by the LED technology provide something extra in terms of attention-getting power, even under the restricted conditions of this test.

It is apparent that there are differences in the two turn modes tested, especially under conditions of a slower cycle time. This can be explained by the fact that the Mode 2 system starts in the full on condition, with a progressive darkening in the desired direction. The Mode 1 system starts in an off condition, so there would be some time before enough columns of LEDs were lighted to attract the attention of the observer in the slower cycle times. This indicates that Mode 2 is preferable for signal application.

In sum, the results of this investigation indicate that signal presentations of the type investigated here, using LED sources, may have advantages in terms of the response time of the following driver. Part of the advantage clearly lies in the rapid rise-time characteristics of the LED. But, part of the differences noted in this study seems to come from the mode of presentation itself. Further work would be required before such systems could be recommended for use on motor vehicles, but the possibility seems worthy of further study.

REFERENCE

Olson, P. L. Evaluation of an LED High-Mounted Signal Lamp. Ann Arbor. The University of Michigan Transportation Research Institute. Report No. UMTRI-87-13, February, 1987.

APPENDIX

TABLE A-1. Photometric Tests on LED Lamp Designed to be Mounted on the Driver's Side of the Test Car

Test Points		Presence: Required Candlepower (FMVSS No. 108 S4.1.1.11 Spec)	Presence: Measured Candlepower Initial	Presence: Measured Candlepower Saturation	Stop: Required Candlepower (FMVSS No. 108 S4.1.1.11 Spec)	Stop: Measured Candlepower Initial	Stop: Measured Candlepower Saturation
10° U	5° L	0.4	9.0	8.3	16	85.6	41.1
	5° R	0.4	9.2	8.5	16	82.7	39.7
5° U	20° L	0.3	4.0	3.7	10	37.2	17.9
	10° L	0.8	9.4	8.7	30	77.9	37.4
	V	1.8	11.3	10.5	70	103.7	49.8
	10° R	0.8	8.5	7.9	30	78.5	37.7
	20° R	0.3	4.0	3.7	10	35.0	16.8
H	10° L	0.8	8.5	7.9	40	78.9	78.9
	5° L	2.0	10.9	10.1	80	99.5	47.8
	V	2.0	11.6	10.7	80	104.5	50.2
	5° R	2.0	11.1	10.3	80	101.0	48.5
	10° R	0.8	8.6	8.0	40	78.3	37.6
5° D	20° L	0.3	3.9	3.6	10	35.8	17.2
	10° L	0.8	8.5	7.9	30	75.6	36.3
	V	1.8	11.1	10.3	70	101.0	48.5
	10° R	0.8	8.4	7.8	30	76.8	36.9
	20° R	0.3	3.9	3.6	10	34.3	16.5
10° D	5° L	0.4	7.9	7.3	16	71.6	34.4
	5° R	0.4	8.1	7.5	16	73.1	35.1
Maximum	Intensity:	18	11.7	10.8	300	104.5	50.2
	Location :		1.2°U-1.1°L			0.5°U-1°R	

Note: Saturation cd represents minimum output achieved after a period of about 1.5 hours.

TABLE A-2. Photometric Tests on LED Lamp Designed to be Mounted on the Passenger Side of the Test Car

Test Points		Presence: Required Candlepower (FMVSS No. 108 S4.1.1.11 Spec)	Presence: Measured Candlepower Initial	Presence: Measured Candlepower Saturation	Stop: Required Candlepower (FMVSS No. 108 S4.1.1.11 Spec)	Stop: Measured Candlepower Initial	Stop: Measured Candlepower Saturation	Minimum Ratio
10° U	5° L	0.4	9.3	8.6	16	88.3	42.4	
	5° R	0.4	7.9	7.3	16	78.9	37.9	
5° U	20° L	0.3	4.5	4.2	10	42.2	20.3	
	10° L	0.8	8.3	7.7	30	77.5	37.2	
	V	1.8	11.0	10.2	70	105.0	50.4	
	10° R	0.8	7.0	6.5	30	69.7	33.5	
	20° R	0.3	3.0	2.8	10	28.1	13.5	
H	10° L	0.8	8.8	8.2	40	83.7	40.2	
	5° L	2.0	11.5	10.6	80	109.3	52.5	
	V	2.0	11.9	11.0	80	115.6	55.5	
	5° R	2.0	9.9	9.2	80	97.7	46.9	
	10° R	0.8	7.4	6.9	40	71.8	34.5	
5° D	20° L	0.3	4.6	4.3	10	43.9	21.1	
	10° L	0.8	9.0	8.3	30	85.6	41.1	
	V	1.8	12.1	11.2	70	118.3	56.8	
	10° R	0.8	7.8	7.2	30	73.1	35.1	
	20° R	0.3	3.0	2.8	10	29.5	14.2	
10° D	5° L	0.4	10.1	9.4	16	94.5	45.4	
	5° R	0.4	9.0	8.3	16	90.0	43.2	
Maximum	Intensity:	18	12.4	11.5	300	121.6	58.4	
	Location :		3.8°D-2.9°L			3.7°D-0.1°L		

Note: Saturation cd represents minimum output achieved after a period of about 1.5 hours.

TABLE A-3. Photometric Tests on Incandescent Lamp Designed to be Mounted on the Driver's Side of the Test Vehicle

Test Points		Presence: Required Candlepower (FMVSS No. 108 S4.1.1.11 Spec)	Presence: Measured Candlepower	Stop: Required Candlepower (FMVSS No. 108 S4.1.1.11 Spec)	Stop: Measured Candlepower	Minimum Ratio	
10° U	5° L	0.7	7.6	19	84.4	3	11.1
	5° R	0.7	7.5	19	85.0	3	11.3
5° U	20° L	0.6	2.3	12	14.0	3	6.0
	10° L	1.4	7.9	36	81.9	3	10.3
	V	3.2	11.2	84	107.1	5	9.5
	10° R	1.4	8.6	36	84.8	3	9.8
	20° R	0.6	2.8	12	21.5	3	7.6
H	10° L	1.4	8.1	48	84.2	3	10.3
	5° L	3.5	10.8	95	117.0	5	10.8
	V	3.5	11.7	95	114.0	5	9.7
	5° R	3.5	10.9	95	118.0	5	10.8
	10° R	1.4	8.9	48	87.5	3	9.8
5° D	20° L	0.6	2.1	12	13.4	3	6.3
	10° L	1.4	7.5	36	76.2	3	10.1
	V	3.2	10.6	84	99.3	3	9.3
	10° R	1.4	8.3	36	79.7	3	9.6
	20° R	0.6	2.7	12	20.5	3	7.5
10° D	5° L	0.7	7.4	19	78.8	3	10.6
	5° R	0.7	7.4	19	79.0	3	10.6
Maximum	Intensity:	20	12.0	360	126.0		
	Location :		H-2.4°R		H-3.7°R		