
LED Stop Lamps Help Reduce the Number and Severity of Automobile Accidents

Application Note 1155-3

NOTE:
Light Emitting Diodes (LEDs) illuminate 200 milliseconds faster than incandescent bulbs – For an automobile this means a faster braking distance response time, about a full car length of extra stopping distance at 65 MPH.

Summary

Another benefit of LED rear brake lamps is their significantly faster turn-on time than conventional incandescent signal lamps. This faster turn-on time provides a safety benefit to the vehicle following the vehicle using faster brake lights in situations requiring fast braking responses. The National Highway Traffic Safety Administration's (NHTSA) *1996 Traffic Safety Facts* estimates that 28% of all accidents are caused by one vehicle rear-ending another vehicle. This is the second largest cause of accidents (the largest cause being angled collisions between two vehicles at 36%). A recent article in Ward's

Auto World quotes Robert Schumacher, Delphi's director of advanced engineering, as follows: "Our research shows that between 37% and 74% of rear-end collisions are preventable by early warning systems.... Just 0.5 seconds [500 ms] in early warning would reduce rear-end collisions by 60%." Two UMTRI studies conclude that LED signals provide a braking response time advantage between 170 and 200 ms under favorable lighting conditions and up to 300 ms under adverse lighting conditions (e.g., viewing at a distance with high-intensity illumination on the lamp surface). Note that a 200 ms improvement in braking response time is equivalent to a 19.1 feet reduction in stopping distance at a speed of 65 MPH.

In addition, the turn-on time for incandescent bulbs is adversely affected by reduced voltage at the signal light. A study by NHTSA of 546 large trucks showed that some trucks have such large voltage drops in the wiring that the voltage across the signal lamp is reduced to voltages in the range of 5.5 to 8.8 V. A study by UMTRI shows that at these reduced voltages, the turn-on times of incandescent bulbs can increase

by as much as a factor of two. This means that braking response time of the following driver would be adversely affected by the response time of the truck's stop lamp. In addition, the light output of the signal light can be reduced to 5% of the nominal value, which could cause the following driver to confuse the tail and stop signal functions. Thus, the use of LED brake lights for heavy trucks would provide an even larger safety benefit than for passenger vehicles.

In addition to the benefits caused by the faster response time of LED brake lamps, another safety benefit is that emergency flashers using LED signal lights reduce the electrical current drain on the car battery. The expected electrical current required for LED signal lights is covered in detail in Application Note 1155-2, "Electrical Power Consumption Savings for LED Signal Lights." Reduced electrical current usage increases the operating time of the flashers as well as reduces the likelihood of a dead battery.

Studies by NHTSA indicate that the braking response time improvement for the use of incandescent bulb Center High

Mount Stop Lamps (CHMSL) is in the range of 90 ms for light trucks and 110 ms for passenger vehicles. NHTSA has evaluated the long-term effectiveness of CHMSL for reducing accidents and concluded that they reduce the incidence of rear-end collisions by 4.33 per cent. At the time the study was done, almost all of the CHMSL on the road used incandescent bulb technology. The report concludes that if every car and light truck had a CHMSL that they would reduce property damage associated with motor vehicle crashes by \$655 million per year. Another NHTSA report concluded that property damage only accounts for 35% to 24% of the complete economic costs due to motor vehicle crashes. Thus, the total economic cost saved by the use of incandescent bulb CHMSL is in the range of \$1.87 billion to \$2.73 billion per year. Considering that there are 192,213,000 registered vehicles during the year of the study, then the total economic cost saving for the use of incandescent bulb CHMSL is in the range of \$9.73 to \$14.19 per vehicle per year. If the average life of a motor vehicle is 10 years, then the total economic savings for the use of an incandescent bulb CHMSL is in the range of \$97 to \$141.

The braking response time due to the use of LED signals is in the order of 200 to 300 ms for passenger vehicles, and even more for large trucks. NHTSA concluded that the braking response time for the use of

incandescent bulb CHMSL is in the range of 90 to 110 ms. Therefore, it is reasonable to assume that the economic cost savings of LED rear brake lights and CHMSLs should be significantly larger in reducing the number and severity of motor vehicle crashes than the economic cost savings of incandescent bulb CHMSLs alone.

Detail

It is generally well known that LED technology has a significantly faster turn-on time than incandescent bulbs. Typical incandescent bulbs used for automotive signal lighting have turn-on times in the range of 100 to 300 ms.^[1] In general, the turn-on of LED lamps is less than 100 ns. Further, LED lamps don't exhibit a high in-rush current, which might further delay the turn-on time. This faster turn-on time provides a safety benefit to the vehicle following the vehicle using faster brake lights in situations requiring fast braking responses. For example, at a speed of 65 miles per hour, a 200 ms faster braking response time from the driver in the following vehicle would reduce the minimum braking distance by:

$$\text{Distance traveled} = (65 \text{ mph})(5280 \text{ feet/mile})(1/3600 \text{ hour/sec})(0.2 \text{ sec})$$

$$\text{Distance traveled} = 19.1 \text{ feet}$$

A number of incandescent bulbs were characterized to determine the turn-on time when driven with a fast rise time circuit. The basic circuit used a high current power supply (>17 A) supplying current to the bulb and power MOSFET switch. The power supply was set to 12.8 V. The power MOSFET had an on resistance of 0.1 ohm and switching speed of 50 ns. The bulb was mounted at the end of a #16 gauge 10 foot wire harness (20 feet supply and return) to simulate the effect of wire inductance that would be experienced in an automotive application. Typical results for one of the bulbs and an LED CHMSL array are shown in Figure 1. The summary of results is shown in Table 1.

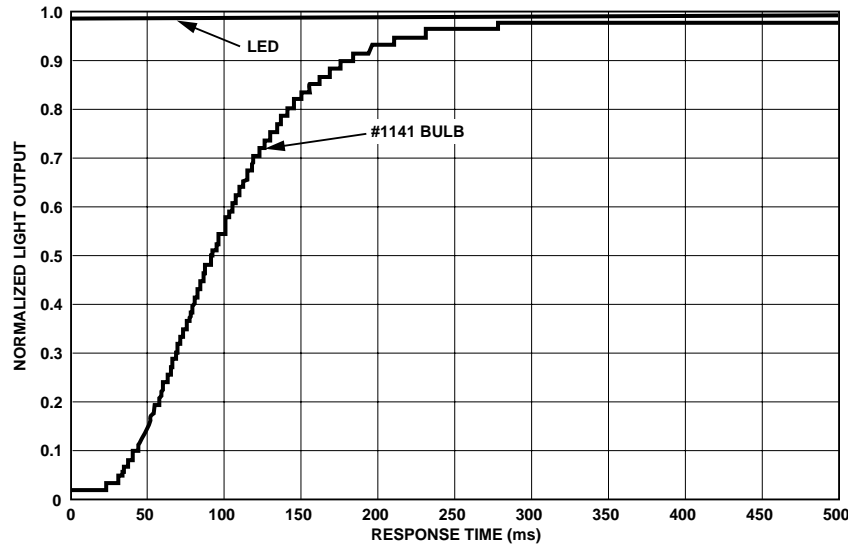


Figure 1. Typical turn-on times of #1141 incandescent filament bulb and LED signal light at 12.8 V.

Table 1. Turn-on time of commonly used automotive signal bulbs.

Bulb type	Application	Design V (V)	Design I (A)	Approximate candlepower (mcsd)	0 to 90% response time (ms)
912	CHMSL	12.8	1.0	12	131
921	CHMSL	12.8	1.4	21	155
922	CHMSL	12.8	0.98	15	118
1141	CHMSL	12.8	1.44	21	164
1156	Rear Stop	12.8	2.1	32	225
1157	Rear Stop	12.8	2.1	32	219
2057	Rear Stop	12.8	2.1	32	218
3057	Rear Stop	12.8	2.1	32	245
3157	Rear Stop	12.8	2.1	32	246

Over the years a number of studies have been made on the braking response times of drivers to LED and incandescent technology automotive stop lamps. One of the first studies was done by the University of Michigan Transportation Institute (UMTRI) and published in their paper 87-13 titled "Evaluation of an LED High-Mounted Signal Lamp." The study compared the braking response times for 20 subjects with ten trials per lamp

in response to an LED stop lamp and an incandescent bulb stop lamp. For their tests, they reported a 60 ns (10% to 90%) turn on time for the LED stop lamp (100 ns, 0 to 90% turn on time) and a 140 ms (10% to 90%) turn on time for the bulb stop lamp (250 ms, 0 to 90% turn on time).^[2] The measured braking response times had a mean braking response time of 430 ms for the LED stop lamp and 690 ms for the bulb stop lamp.^[3] The following is a quote

from their paper:

The results of this investigation provide evidence that the LED HHSL has a significant advantage over the conventional incandescent HMSL in terms of the response time of following drivers. The rise-time characteristics of the two types of lamps led to an expected response time difference of about 0.14 second. Under the conditions

of this test that were most favorable for viewing light signals, the LED units provided a response time advantage slightly greater than expected, about 0.20 second. Under less favorable conditions (e.g., viewing at a distance, high-intensity illumination on the lamp surface) the attention-getting properties of the LED units appear to be less affected than those of the incandescent units, and the response time advantage increased to about 0.30 second.

The fact that the response time advantage enjoyed by LED signal lamps is greater than would be predicted based on their rise-time characteristics suggests that they may have greater conspicuity than incandescent sources of the same intensity. This greater conspicuity may be attributable to the LED's brief rise-time. That is, a lamp that quickly reaches maximum output may have better attention-getting characteristics than one that takes a longer time to reach maximum output.^[4]

UMTRI published a second paper, 93-37, titled "Reaction times to Neon, LED, and Fast Incandescent Brake Lamps." The study compared the braking response times for 16 subjects with eight trials per lamp. Each of the "fast" signal lamps was compared to the braking response of a #1157 bulb. The fast incandescent lamp was created by driving the standard #1157 bulb with a special circuit that kept the filament warm prior to the turn-on of the bulb and generated a brief over voltage at the time of turn-on. The measured braking response time had a mean

braking response time of 503 ms for the LED stop lamp and 662 ms for the standard #1157 stop lamp.^[5] In addition, the paper examined the distribution of the reaction times and found that the distributions were positively skewed (i.e., there were more long reaction times than expected with a normal distribution). The subjects had 8.4% of their braking response times in excess of one second with the standard incandescent bulb stop lamp, and 3.4% of their responses greater than one second for the LED stop lamp.^[6] Thus, in addition to improving the average braking response times, the use of LED stop lamps can be expected to reduce the cases of a missed braking signal. The following is a quote from their paper:

The main finding of this study is that there are several viable alternatives to the standard incandescent brake lamps, all leading to substantially shorter reaction times. The neon, LED, and fast incandescent bulbs all yielded shorter reaction times than did the standard incandescent lamps. The fastest reaction times were obtained from both the neon and the LED lamps, followed by the fast incandescent lamp. Averaged over both levels of luminous intensity, the difference between the neon and LED lamps, on the one hand, and the standard incandescent lamp, on the other hand, averaged 166 ms.^[7]

A nonparametric analysis of very long reaction times confirmed the advantage of the neon, LED, and fast incandescent lamps. Specifically, there were substantially fewer reaction

times that were longer than one second for the neon, LED, and fast incandescent lamps than for the standard incandescent lamp.^[8]

During the Society of Automotive Engineers International Exposition trade show for 1991 through 1993, Hewlett-Packard had a demonstration unit that allowed a show attendee to compare his braking response times due to an LED CHMSL versus an incandescent CHMSL. Over the three-year period, 790 people participated in the study. The demo consisted of a car "buck" based on a Ford Taurus front seat, dashboard, steering wheel, and brake and gas pedals. Mounted in front of the car "buck" were four CHMSLs that were turned on pseudo randomly by a microprocessor controller. The LED CHMSLs used an array of HPWA-MH00 LED lamps. The bulb CHMSL used several #1141 bulbs. The microprocessor controller measured the delay time from the instant that power was applied to the signal until the time that the brake pedal was depressed. Each participant underwent six trials, consisting of three each LED and bulb signals. As the demo was designed for entertainment and not for scientific research, the trials were not as well controlled as either of the UMTRI studies cited earlier.

The average results are shown in Figure 2. This graph shows the mean braking response times with all data points greater than 1.2 seconds removed from the data set. Note that the braking response times improved for each successive trial. However, comparing the LED to incandescent average braking response times at each trial

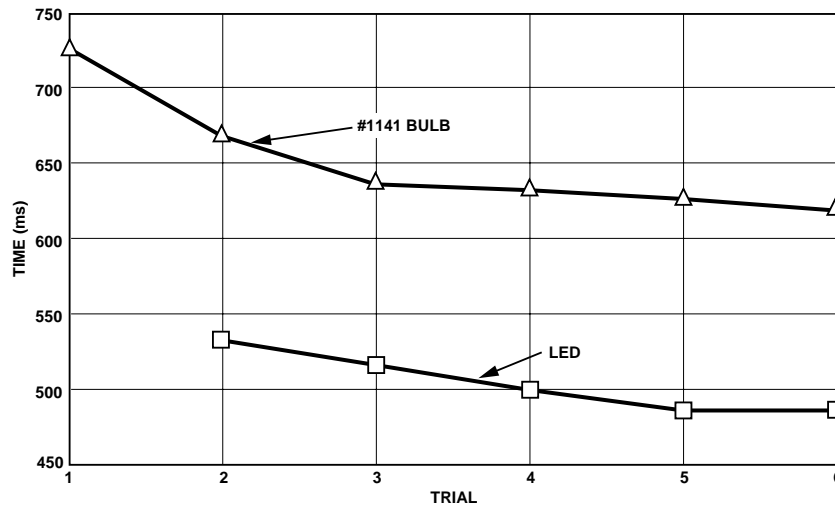


Figure 2. Average braking response times of #1141 incandescent bulb CHMSL and LED CHMSL at Hewlett-Packard trade show booth during 1991, 1992, and 1993 SAE International Exhibition.

Table 2. Voltage at brake lamps for a sample of 546 large trucks (adapted from Copenhaver et al., 1990)[10]

Vehicle Type	Min. (V)	Max. (V)	Mean (V)	Standard Deviation (V)
Dump trucks	10.3	13.1	12.2	0.8
Vans	8.8	13.8	11.6	1.0
Tankers	7.5	13.4	11.5	1.2
Flat-beds	6.5	13.2	11.4	1.2
Double Trailers	6.0	12.4	9.8	1.5
Triple Trailers	5.5	11.1	8.4	1.6

results in an average braking response time reduction of 130 ms.

Besides their generally slower turn-on times, bulbs have the further disadvantage that their turn-on times are further increased when they are driven at lower voltages. This can be especially a problem due to the voltage drop in the wiring harness. By comparison, the turn-on time of LED lamps is relatively insensitive to drive current. The U.S. Department of Transportation studied 546 large trucks (Copenhaver, Guirrier, and

Ching, 1990).[9] At idle speed the voltages measured at the signal lights were substantially less than the nominal ignition voltage as shown in Table 2. The following table is summarized from their paper.

UMTRI has published another paper, 93-28, titled "Effects of Voltage Drop on Rise Time and Light Output of Incandescent Brake Lamps on Trucks." This study measured the turn-on time and luminous intensity (through a red filter) for an #1157 bulb at voltages lower than its 12.8 V design voltage. The results are

summarized in Table 3.

Reaction time to the onset of light stimuli increases with either an increase in the rise time of the stimulus (Flanagan and Sivak, 1989), or a decrease in the intensity of the stimulus (Teichner and Krebs, 1972). Consequently, the obtained changes in rise time and light output of incandescent lamps as a function of voltage are of practical importance. Reduced voltage can be expected to cause an increase in reaction times of following drivers to brake signals. Furthermore, the reduced light output will likely result in an increase in the frequency of missed brake signals.[12]

Thus the use of an LED signal lamp provides an improved braking response time on the order of 200 ms as compared to a conventional incandescent signal lamp. In addition, the faster rise time of the LED signal lamp is more attention getting than the slower rise time of a conventional incandescent signal lamp. The difficulty is in equating these benefits for LED signal lamps into cost savings either for the car manufacturer or car owner.

NTHSA has evaluated the different causes of accidents. Their technical report, DOT HS 808 649, titled "Traffic Safety Facts 1996", estimates that 28% of all accidents are caused by one vehicle rear-ending another vehicle. This is the second largest cause of accidents. The largest cause of accidents at 36% is one vehicle colliding with a second vehicle in an angled collision. These types of collisions are much more frequent than single-

Table 3. Turn-on time and normalized luminous intensity of #1157 bulb at reduced voltages.[11]

Voltage	0 to 90% turn-on time (ms)	Normalized Luminous Intensity
12.8	259	1.00
12	282	0.79
11	294	0.59
10	320	0.42
9	372	0.28
8	410	0.18
7	487	0.10
6	575	0.05

car collisions with a fixed object (i.e., post, ditch, tree, guard rail, embankment, etc.) at 15% or collisions with an unfixed object (i.e. parked car, animal, pedestrian, bicycle, train, etc.) at 12%.[13]

A recent article in Ward's Auto World quotes Robert Schumacher, Delphi's director of advanced engineering, as follows: "Our research shows that between 37% and 74% of rear-end collisions are preventable by early warning systems." Mr. Schumacher tells a group of journalists during a future technology seminar at Delphi headquarters in Troy, MI. "Just 0.5 seconds [500 ms] in early warning would reduce rear-end collisions by 60%." [14]

Several years ago, the National Highway Traffic Safety Administration (NHTSA) mandated the use of center high-mounted stop lamps (CHMSL) on passenger cars and light trucks. Their initial studies showed a reduction in accidents due to the faster braking response time of following cars and improved conspicuity of the signal lamp. Following the promulgation of the CHMSL, NHTSA has further

evaluated the cost effectiveness of the CHMSL in reducing accidents.

In 1998, NHTSA published a technical report, DOT HS 808 696, titled "The Long-term Effectiveness of Center High Mounted Stop Lamps in Passenger Cars and Light Trucks." This report compares the accident statistics of cars and light trucks equipped with CHMSLs versus similar vehicles without them. At the time the study was done, almost all vehicles on the road used incandescent bulb technology CHMSLs. The report determined that "the most important finding of the evaluation is that, in the long term, passenger car CHMSLs reduce rear impacts by 4.3 per cent (confidence bounds: 2.9 to 5.8 per cent)." [15]

Quoting from the NHTSA report, cited earlier:

In 1988, NHTSA conducted extensive tests of the reaction times of volunteers to simulated light trucks with CHMSL or with conventional brake lights. The reaction time for drivers following a truck

with CHMSL was 0.09 seconds shorter than for drivers following a truck without CHMSL. That is just a slightly lower benefit than in passenger cars, where the reduction in reaction time with CHMSL was 0.11 seconds.[16]

The NHTSA report gives several hypotheses why CHMSL might stimulate a quicker reaction time than conventional stop lamps. These hypotheses include:

1. Central raised location being in the central field of view of the driver.
2. Lack of ambiguity in the meaning of the signal.
3. High mounting location is generally visible through the windows of a following vehicle allowing a third vehicle in a chain to react to the braking of the first car.
4. Interpretation of the signal as a warning, causing following drivers to follow at a safer distance.

Based on an average rear collision accident reduction rate of 4.33 per cent, the NHTSA report concluded that:

When all cars and light trucks have CHMSL, the lamps will prevent an estimated 92,000 - 137,000 police-reported crashes per year, and approximately 102,000 unreported crashes. CHMSL will reduce property damage and its associated societal costs by approximately \$655,000,000 per year (in 1994 dollars) in reported and unreported crashes. The lamps will prevent 58,000 - 70,000 injuries per year. [17]

The NHTSA report, DOT HS 808 649 titled "Traffic Safety Facts 1996", estimates that in 1994 there were 192,213,000 registered vehicles and 2,358 billion miles traveled.^[18] Thus, the incandescent bulb CHMSL can be expected to reduce property damage by $(\$655,000,000 / 192,213,000)$ or \$3.40 per vehicle per year or $(\$655,000,000 / 2,358 \text{ billion miles})$ or \$0.278 per 1000 miles driven per year. If the average life of a vehicle is 10 years, the use of incandescent bulb CHMSLs can be expected to reduce property damage by \$34.

Property damage is only one of the many economic costs of motor vehicle crashes. The NHTSA report, DOT HS 808 425, titled "The Economic Cost of Motor Vehicle Crashes", evaluated the total economic costs. These costs include property damage costs, productivity losses, medical costs, rehabilitation costs, travel delay costs, legal and court costs, emergency service costs, insurance and administration costs, funeral costs, and costs to employers. On average for all types of motor vehicle crashes, property damage costs only account for 35% of the total economic costs.^[19] For motor vehicle crashes with non-fatal injuries only, property damage accounts for only 24% of the total economic costs.^[20] Accounting for these other economic costs and assuming that the average car has a 10 year life, then the total economic cost savings of the incandescent bulb CHMSL is about \$135.

The braking response time reduction for LED signal lights is on the order of 200 to 300 ms for passenger vehicles and even more

for heavy trucks. The NHTSA report concluded that the braking response time of incandescent bulb CHMSL is in the range of 90 to 110 ms. Thus, it is reasonable to assume that the economic cost savings of LED rear brake lights and CHMSLs in reducing the number and severity of motor vehicle crashes should be significantly larger than the economic cost savings of incandescent bulb CHMSLs alone.

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