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LED TECHNOLOGY FOR IMPROVED CONSPICUITY OF SIGNAL LIGHTS AT HIGHWAY-RAILWAY GRADE CROSSINGS

Prepared for

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by

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February 2003

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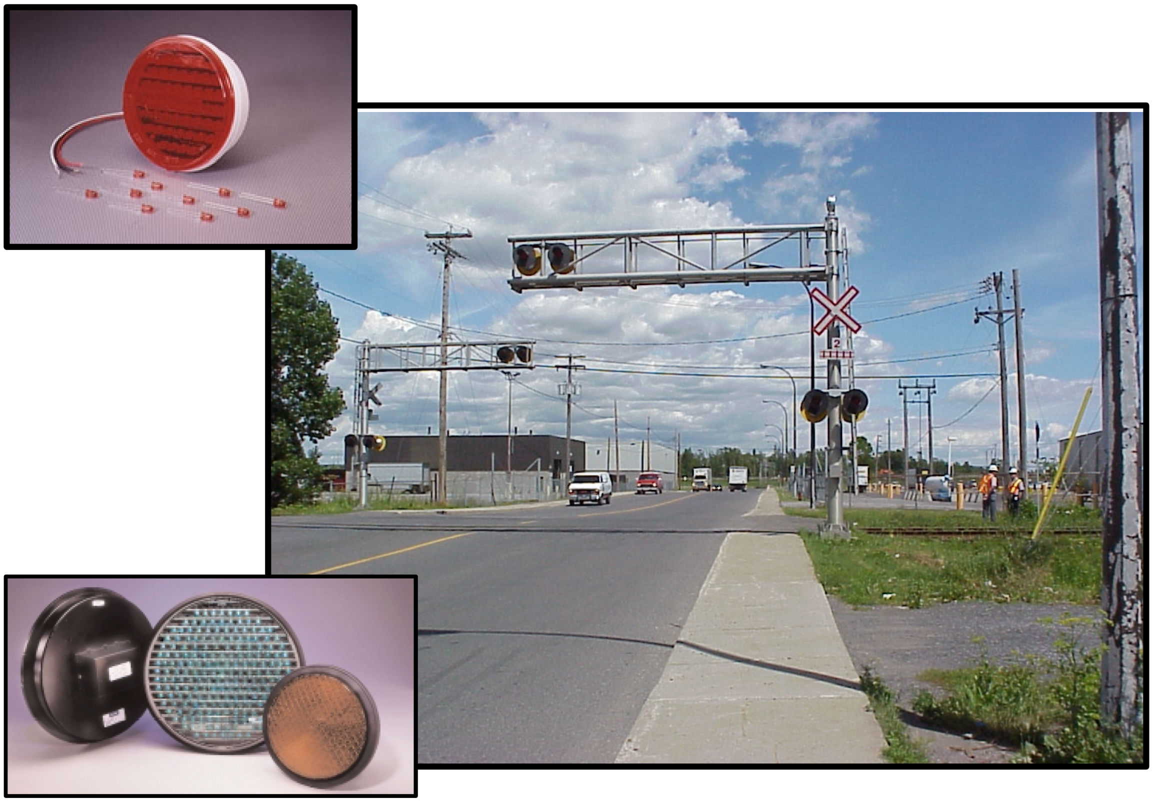

by

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NOTICES

Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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16. Abstract

The purpose of this project was to establish a national performance standard for LED signal lights at highway-railway grade crossings.

The project first examined the existing performance standards for incandescent signal lights for grade crossings and traffic lights. In consultation with a broad spectrum of stakeholders, basic criteria were established for a new standard that would apply to LED signal lights at grade crossings.

The scientific and technical literature on LEDs, human factors, and driver requirements was then summarized and analyzed, resulting in a tentative performance standard that specified light output and beam pattern, as well as electrical, mechanical and quality assurance requirements.

This standard was tested in the laboratory and in three field experiments to determine its feasibility and its effectiveness relative to existing incandescent signal lights. The results showed that the performance requirements could be met by existing LED technology, and clearly demonstrated the superior performance of the LED signal lights.

The standard requires that LED signal lights produce 400 cd light output, on axis, under all conditions likely to be encountered in the field and over the lifetime of the product. The beam pattern must equal or exceed international traffic light requirements, resulting in a much broader beam pattern than existing railway requirements.

In conclusion, a verifiable performance standard was developed that provides for improved conspicuity of grade crossing signal lights through the adoption of LED technology.

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16. Résumé

L'intention du projet était d'établir une norme de performance nationale visant les feux de signalisation à diodes électroluminescentes (DEL) aux passages à niveau.

La première phase du projet consistait à examiner les normes courantes de performance des signaux lumineux à incandescence utilisés aux passages à niveau et en signalisation routière. En consultation avec une large coupe de groupes intéressés, on a défini les critères de base d'une nouvelle norme qui s'appliquerait aux feux à DEL destinés aux passages à niveau.

Il a fallu ensuite mener une recherche documentaire scientifique et technique sur les DEL, sur les facteurs humains et sur les besoins des conducteurs. Les documents ont été résumés puis analysés, ce qui a débouché sur un projet de norme de performance renfermant des spécifications concernant l'intensité lumineuse et la forme du faisceau de lumière, de même que des exigences relatives aux composants électriques, aux composants mécaniques et à l'assurance de la qualité.

La norme a fait l'objet d'essais en laboratoire et de trois expériences sur le terrain. Le but était de déterminer la faisabilité de la norme puis de comparer les feux de signalisation à DEL avec les feux existants, à incandescence, pour évaluer l'efficacité de la norme. Les résultats ont indiqué que la technologie DEL actuelle pourrait satisfaire aux conditions énoncées, et ils ont démontré clairement qu'elle donne une performance supérieure.

Selon la norme, les feux de signalisation devront produire une intensité lumineuse de 400 cd, mesurée dans l'axe du faisceau lumineux, et ce, dans toutes les conditions possibles de service et pendant toute la durée de vie du produit. La forme du faisceau doit présenter des caractéristiques égales ou supérieures à celles prévues par les exigences internationales concernant les feux de circulation routière, ce qui signifie une distribution de lumière plus étendue qu'avec les feux de signalisation ferroviaire existants.

Le projet a permis d'élaborer une norme de performance vérifiable pour la mise en place de feux à DEL afin de garantir une meilleure perceptibilité des signaux lumineux aux passages à niveau.

17. Mots clés: Passage à niveau, diode électroluminescente, DEL, norme, feux de signalisation, signaux lumineux, passage à niveau, intensité lumineuse, faisceau lumineux, spécifications photométriques

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EXECUTIVE SUMMARY

Highway-railway crossings present a significant hazard to drivers, resulting in approximately 300 accidents and 50 fatalities per year in Canada. Signal lights that are activated by the approach of a train are the most important component of crossing warning systems. Recent improvements in light-emitting diode (LED) technology have allowed the development of LED lights that are more conspicuous than the existing incandescent lights, while offering important operational advantages. Transport Canada has restricted the use of LED signal lights in Canada pending the development of a suitable, justifiable standard. This document is the result of a year-long study to develop such a standard.

Background

In general, one would expect highway-railway crossing lights and traffic signal lights to be similar in their specifications, since they perform nearly identical tasks of bringing traffic to a stop. However, railway crossing lights differ from highway traffic lights in one key respect: by regulation, railway lights must be able to run from battery backup for considerable lengths of time in the event that the power from the electrical grid is lost. There is no similar requirement for highway signals. As a result, traffic lights on high-speed roads use 150 W bulbs, whereas railway lights use 18 W bulbs to save on energy consumption.

In order to get sufficient intensity from an 18 W bulb, railway lights use a parabolic mirror to create a focussed beam that is aimed at the motorist. Beam patterns therefore differ dramatically between traffic lights and railway lights, with railway lights having a much narrower and more focussed beam. These narrow beams require precise alignment of the light bulbs, as well as of the signal housings, which in turn requires substantial structures to hold the signal housings precisely in alignment.

LED technology offers greatly increased energy efficiency, allowing the ‘bar to be raised’ on light output specifications for railway crossing lights, thereby increasing driver safety.

Stakeholder Consultation

In order to determine how best to ‘raise the bar’ on railway light specifications, this study consulted widely with railway and traffic regulatory authorities, with the railway industry, with the scientific community, and with the manufacturers of railway and traffic signal lights. A steering committee with representatives from each of these stakeholders met regularly throughout this project, and the interim reports and the draft standards were posted on the web (railwaycrossings.com) for review and comment by a wider audience.

The following principles and goals were established from the stakeholder consultation process and were used to guide the development of the standard. The stakeholders agreed that the standard should:

- be based on drivers’ requirements and human factors considerations;
- define a broad beam pattern so alignment is not critical and standard traffic light structures can be used;
- meet or exceed existing highway-railway crossing signal light requirements as expressed in the latest version of the recommended specifications for incandescent lights;
- meet or exceed the most demanding high-speed, wide-angle traffic light specifications;

- be a universal specification for front, back and overhead lighting to avoid requiring different signal modules for each location;
- be a measurable, quantifiable standard that can be applied throughout the life of the signal;
- be confirmed with laboratory and field testing;
- be the same specification for 200 mm and 300 mm lights.

Review of Standards

The study began with a review and comparison of railway and traffic light standards, and how they have evolved over the years. The scientific literature was also reviewed and summarized to show how the standards were derived. The review of standards provided the baseline information for the proposed new standard.

Discussion of Human Factors

It was important to review the scientific literature on LED light sources to determine whether the light produced by LEDs would be less conspicuous than that produced by incandescent light, thereby requiring the specification to be increased over the incandescent requirements. A review was conducted of the characteristics of light produced by red LEDs versus light produced by red-filtered incandescent bulbs. These characteristics were examined for how they would affect colour deficient individuals, drivers wearing sunglasses, aging eyes, visibility when drivers are subjected to a sun phantom effect, and visibility in fog. The review concluded that LED signal modules can be expected to outperform incandescent signals with the same luminous intensity because of two inherent advantages:

1) LED signals produce a pure red signal that is more conspicuous to the human eye.
2) LED signals can turn on and off instantaneously (as long as this characteristic is not compromised by the LED power supply), which improves the range at which flashing lights can be seen.

Accordingly, LED signals can be expected to provide an additional margin of conspicuity over incandescent light sources with the same luminous intensity.

The review of human factors also provided an important upper limit on the luminous intensity at night, which is the key upper limit on the light output that can be required of signal lights.

Discussion of Driver Requirements

A review of driver requirements at railway crossings was conducted to determine whether there were any driver requirements at highway-railway crossings that were clearly different from driver requirements at highway traffic lights. The review concluded that traffic light specifications were well suited to railway crossing applications, and that there were no fundamental reasons for the specifications for the two applications to differ.

Discussion of Laboratory Tests

A concern in setting the standard was that it would be set so high that manufacturers would not be able to meet the standard. A number of versions of LED signal lights, usually prototypes, were obtained from a variety of manufacturers. Four were tested against all aspects of the proposed standard. The laboratory tests showed the standard could be met by three of the manufacturers with minor modifications to their power supplies, and that they could use existing lenses designed for traffic lights to meet the beam pattern requirements.

Discussion of Field Experiments

Railway crossing guidelines for incandescent lights specify the visible range of the lights, which is something that can only be determined by field experiments. The final step in the project was to conduct three different field tests with three different focus groups. The field tests showed that LED signal lights with the required luminous intensity easily exceeded the visible range requirements. As well, the field experiments clearly demonstrated the superiority of the LED signal lights over traditional incandescent lights.

Description of the Standard

The recommended standard brings railway signal lights into conformance with high-speed, wide-angle traffic light specifications in North America and Europe.

Additionally, the recommended traffic light beam pattern is sufficiently broad and universal to allow a single LED signal module design to meet the performance requirements for overhead lights, lights to the side of the road, and ‘back lights’ on the far side of the track, thereby eliminating the requirement for different roundels for each application. The broad beam will also significantly reduce the need for checking signal alignment, and will allow cheaper and safer traffic light structures to be used to mount the signal housings.

A key premise of this standard is that it is a ‘maintained’ standard that must be met throughout the operational life of the unit and under all normal operating conditions, including when operating from battery backup. Using a ‘maintained’ standard, signal modules can be tested at any time to ensure that they continue to meet the intensity and beam pattern requirements.

Implementation of the Standard

The key photometric specifications developed in this study are intended to be published in Transport Canada’s RTD 10, Road/Railway Grade Crossings, as a national standard.

A second document, a purchase specification, was also prepared. The purchase specification contains detailed electrical, mechanical, environmental and quality assurance requirements designed to ensure that LED signal models will meet the photometric specifications in the standard under all normal operating conditions currently found on Canadian railways.

The implementation of this new standard for LED signal lights will result in the performance of highway-railway crossing lights increasing to the same level as high-speed, wide-angle traffic signal lights, and will thereby increase driver safety.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Light emitting diodes (LEDs) are a new, reliable and rugged technology that offers much more efficient lighting for some types of applications. The use of LEDs in applications such as navigation lights, traffic lights, and brake lights on vehicles is proceeding rapidly. The rate of change in LED technology has made it difficult for regulatory bodies to keep up, but it is evident that LEDs offer very important improvements in reliability and in power consumption, and that their use should be encouraged. For traffic light applications, LED modules are being used to reduce energy consumption while still meeting the standards required of traditional incandescent light sources. With railway crossing signal lights, LEDs offer the chance to improve performance without increasing energy consumption.

Transport Canada has the responsibility for ensuring that good standards are in place for highway-railway crossing lights. Recognizing the improvements in safety and reliability that LEDs can offer, Transport Canada has contracted with Carmanah Technologies Inc. to examine the existing standards used in Canada for lights at highway-railway crossings, and recommend changes that will take advantage of the new LED technology.

This report reviews railway crossing and highway traffic light standards in North America and elsewhere in the world, human factors relevant to the use of LEDs in warning lights, driver requirements, the scientific literature, and the results of consultations with stakeholders. These sources of information narrow the range of luminous intensity for the LED standard to a relatively narrow range. A series of laboratory and field experiments is then summarized, which leads to the conclusion regarding the photometric requirements for LED crossing signals. The full text of the standard is proposed, including the physical, mechanical, electrical and environmental requirements, and the quality assurance procedures recommended to ensure compliance with the standard.

The key requirements that are unlikely to change over the foreseeable future are written into the recommended standard, which is included in its entirety as Appendix A. A more detailed purchase specification, which includes items that may change with advancing technology, is included as Appendix B.

2. CURRENT STATUS OF PHOTOMETRIC SPECIFICATIONS FOR CROSSING SIGNALS

Highway-railway grade crossings present the railway industry with a difficult safety issue: how to share its right-of-way with roads. Since trains cannot easily stop, the danger at highway-railway crossings is high. Approximately 40-50 people are killed each year at highway-railway crossings in Canada, accounting for about half of all railway fatalities and about 1.3% of all highway accidents (Transport Canada, 1996 and 1998). The railway industry long ago developed a warning system that includes lights for marking highway-railway crossings, so as to provide drivers with as much advance warning as possible of an approaching train (see Figure 1 and Figure 2). Nevertheless, about half of the railway crossing fatalities (about 20 fatalities per year in Canada) are at crossings equipped with these warning systems.

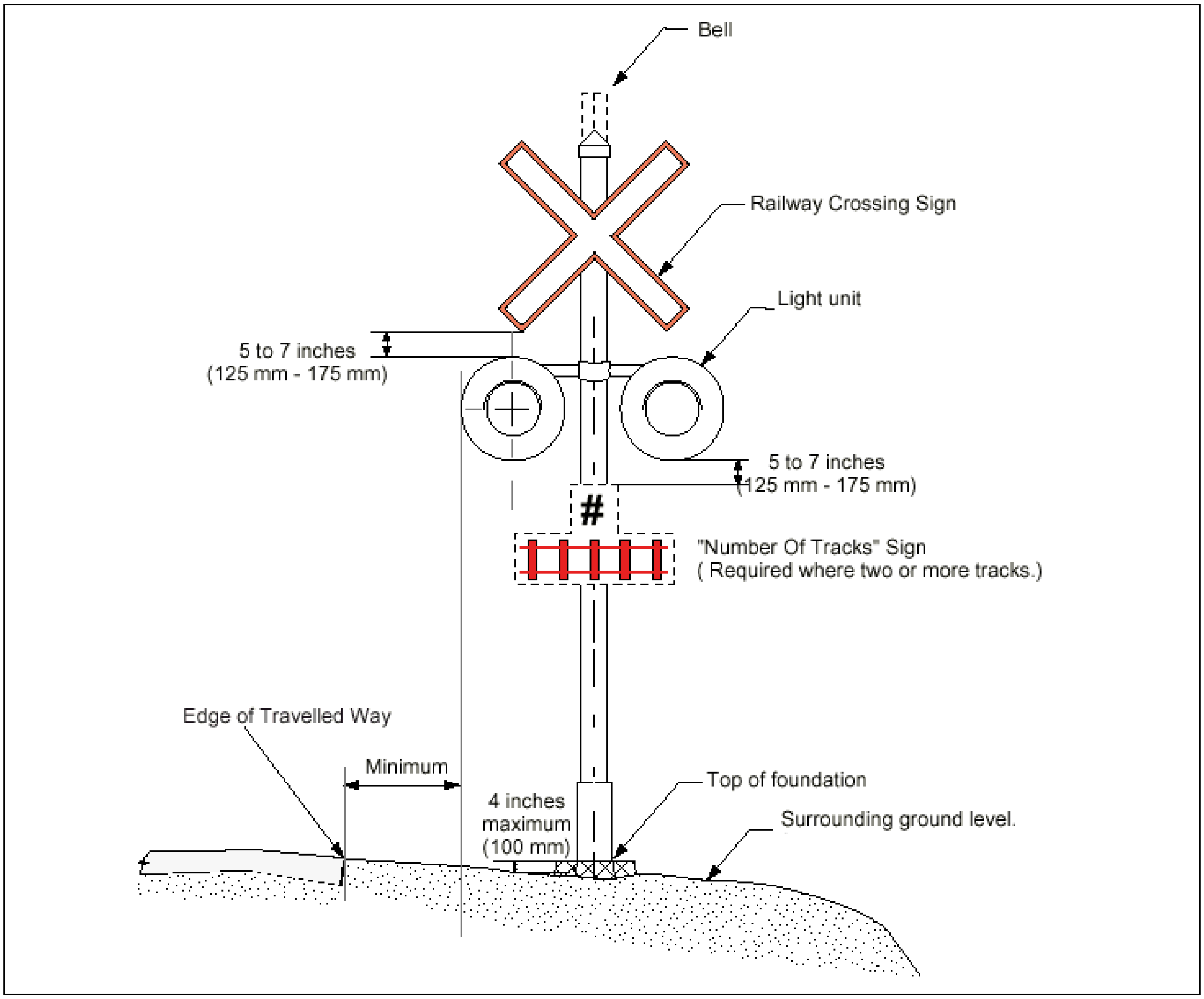


Figure 1 Warning Signal (Part C – *Grade Crossing Warning System Technical Requirements*, RTD 10 Road/Railway Grade Crossings, Draft, March 7, 2002)

In order to ensure that the warning system is operational even in the event of a power failure, the railway lighting system, unlike the highway traffic light system, uses battery backup to provide sufficient power to run the crossing light system for approximately 10 hours of continuous operation (AREMA Manual Part 3.1.28, 1999; CN Codes of Practice, 2000). The requirement that the lighting system be able to function for extended periods on battery power has major implications for the design of the lighting system.

Leadership in providing specifications for highway-railway grade crossing lights has rested with the Association of American Railroads (AAR) for many years, and has more recently been assumed by the American Railway Engineering and Maintenance-of-Way Association (AREMA). Transport Canada has, in the past, relied mainly upon these specifications for regulating crossing lights in Canada. There are about 6000 ‘active’ railway crossings in Canada that have lighting systems. The cost of installation and maintenance of these sites is paid by road authorities and the railways under cost-sharing arrangements, with Transport Canada contributing toward some installations through the Grade Crossing Improvement Fund.

Crossing lights are designed to run from a battery bank at an effective voltage of 10 V. The wattage of the bulbs in the lights is nominally 18 W. By way of comparison, a 300 mm standard traffic light uses a 150 W bulb running on 120 V AC powered by the electrical grid.

Since the wattage of the railway bulb is only a fraction of the wattage of a traffic light, the railway industry has had to use a different lighting system than is used in traffic lights in order to get enough range from the bulb. The solution has been a focused parabolic mirror, with the bulb at the focal point. This produces a very bright, narrow beam resembling a searchlight, typically with a brightness of 1600 cd in the centre of the beam when the light is first installed. This beam then has to be focused on the road at the appropriate distance from the rail line to provide the motorist with sufficient warning to stop. The aiming distance of the railway light varies depending on the speed of the approaching traffic up to a maximum of about 300 m.

The requirement for focusing and aiming the railway light is a complex maintenance procedure. Both the focusing and alignment can be affected by temperature, vibration, collisions with the posts, cleaning procedures, etc. The structure required for the railway light also has to be very rigid, since a tilt of a few degrees will throw off the alignment of the signal. This requirement for a solid structure compromises safety in other ways. The post system itself becomes a hazard, and it is difficult to place the light out over the traffic as is done with traffic lights, since a cantilevered structure is required that is strong enough to hold the signal rigid, as well as accommodate the weight of a technician when aligning the signal.

The narrow beam approach is typical for railway engineers: the light signals used on the railway line itself for the benefit of the train have a very narrow beam. Since all trains place their motorists at the same height, and since the motorists are all constrained to a track only about a metre wide, the aiming of the signal is a straightforward exercise. However, when this same technology is used on roads, the target drivers may be coming from a wide variety of directions, be seated at different heights, and be dealing with many more distractions than the driver of a train.

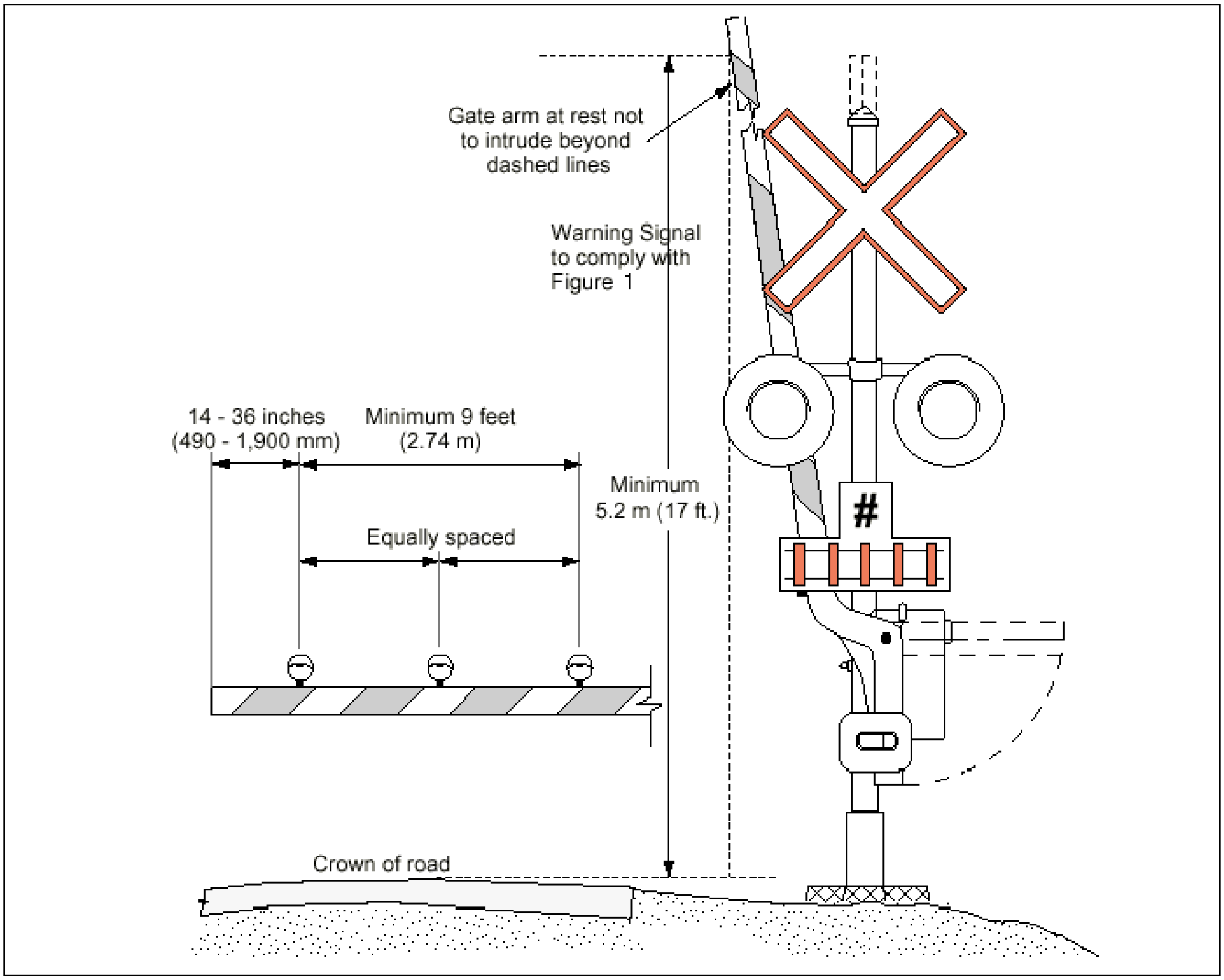


Figure 2 Warning Signal with Gate (Part C – *Grade Crossing Warning System Technical Requirements*, RTD 10 Road/Railway Grade Crossings, Draft, March 7, 2002)

Since the beam produced by the signal is narrow, it is common to use lenses that are intended to spread the light for the highway crossing application. The various lenses are called roundels, and have numbers that describe their beam patterns. Although these roundels spread the beam of light horizontally, the resulting beams are still narrow in the vertical direction.

The progression of AAR and AREMA standards used to regulate the brightness and beam pattern of highway-railway crossing lights has been summarized by McKnight, 1999. The first specification on record in that summary was written in 1966, and specifies the range at which the various roundels in use could be seen.

The text of that standard was as follows:

1966: AAR Manual Part 166 (specification for electric light unit for highway crossing signal)

Range shall be the distance at which, under bright sunlight conditions with the sun at or near the zenith, the indication will be clear and distinct to a person with normal vision. The range shall be determined when the light unit is operated with a signal filament lamp of 1000 hrs design burning at 10 V.

- when equipped with a 30° horizontal spread, 15° downward deflection roundel, the range shall be, in feet (typically front lights at the crossing)

Range (Feet) for Incandescent Lamps with 30-15 Lens

	15°L	10°L	5°L	0°	5°R	10°R	15°R
0°	500	1500	1500	1500	1500	1500	500
5° D				not specified			
10° D				n.s.			
15° D				n.s.			

- when equipped with a 70° horizontal spreadlight roundel without downward deflection, the range shall be, in feet (typically back lights at the crossing)

Range (Feet) for Incandescent Lamps with 70 lens

	35°L	30°L	25°L	20°L	15°L	10°L	5°L	0°	5°R	10°R	15°R	20°R	25°R	30°R	35°R
0°	200	300	500	600	700	900	1300	1500	1300	900	700	600	500	300	200

- for cantilever-mounted signals and mast-mounted signals higher than 9 feet when equipped with a 20° horizontal spread, 32° downward deflection roundel, the range shall be:

Range (Feet) for Incandescent Lamps with 20-32 lens

	15°L	10°L	5°L	0°	5°R	10°R	15°R
0°	500	1500	1500	1500	1500	1500	500
5° D				not specified			
10° D				n.s.			
15° D				n.s.			
20° D				n.s.			
25° D				n.s.			
30° D				n.s.			
35° D				n.s.			

In 1968 a study was done of the light output of various signal lights that met the range requirements. This information was then used to develop the following specifications, which were introduced in 1970, in which the range requirements were converted to candela (or candlepower). The requirements for the candela output of the various roundels were specified in the horizontal direction. Although the lens designs were intended to deflect light in the vertical direction, no light output or beam pattern was specified in the vertical direction.

1970 AAR 1970 Manual Part 166 (specification for electric light unit for highway crossing signal)

The roundels shall be highway crossing signal red, 8-3/8 inch in diameter, convex, and in accordance with Manual Part 136.

Beam pattern shall be determined when the light unit is operated with a 10 V, 18 W CC6 filament lamp, burning at 10 V, in accordance with Manual Part 91, Item 88.

Minimum beam pattern, in beam candlepower (red), shall be in accordance with roundel specification for the following table.

Minimum Luminous Intensity (cd) for Incandescent Lamps – Long Range 30-15 Lens

	15^OL	10^OL	5^OL	0^O	5^OR	10^OR	15^OR
0^O	100	200	350	1100	350	200	100
5^O D				ns			
10^O D				ns			
15^O D				ns			

Minimum Luminous Intensity (cd) for Incandescent Lamps – Long Range 70 Lens

	30^OL	25^OL	20^OL	15^OL	10^OL	5^OL	0^O	5^OR	10^OR	15^OR	20^OR	25^OR	30^OR
0^O	-	25	45	75	125	500	1600	500	125	75	45	25	--

Minimum Luminous Intensity (cd) for Incandescent Lamps – 20-32 Lens (not long range)

	10^OL	5^OL	0^O	5^OR	10^OR
0^O	50	150	250	150	50
5^O D			ns		
10^O D			ns		
15^O D			ns		
20^O D			ns		
30^O D			ns		

This standard was repeated in 1974, in 1975, and in 1984 according to the records provided by McKnight. In 1991 the standard was changed, although there is no explanation as to why the change occurred. The beam pattern specified was considerably broader, and for the first time the vertical beam pattern was specified.

1991 AAR Luminous Intensity & Distribution Standard for Incandescent Crossing Lights (Part 3.2.35)

(both 8 3/8 inch and 12 inch units)

Minimum Luminous Intensity (cd) for Incandescent Lamps – 30-15 Lens

	15^OL	10^OL	5^OL	0^O	5^OR	10^OR	15^OR
0^O	200	500	1000	1600	1000	500	200
5^O D				35			
10^O D				25			
15^O D				15			

Minimum Luminous Intensity (cd) for Incandescent Lamps – 70 Lens

	30^OL	25^OL	20^OL	15^OL	10^OL	5^OL	0^O	5^OR	10^OR	15^OR	20^OR	25^OR	30^OR
0^O	10	25	150	250	400	800	1200	800	400	250	150	25	10

Minimum Luminous Intensity (cd) for Incandescent Lamps – 20-32 Lens

	10^OL	5^OL	0^O	5^OR	10^OR
0^O	500	1000	1600	1000	500
5^O D			40		
10^O D			25		
15^O D			15		
20^O D			10		
30^O D			5		

These same standards were repeated in 1995, with no change.

In 1996, AAR introduced a standard for LED signals. The on-axis requirements were reduced dramatically from 1200 cd or 1600 cd (depending on the roundel) to 160 cd, in order to accommodate the lower brightness and broader beam that could be achieved with the LED technology at the time. The beam of light was circular, and was far broader in the vertical direction than the narrow horizontal beam produced by the incandescent technology.

The standard reads as follows:

1996 AAR Luminous Intensity & Distribution Standard for LED Crossing Lights (Part 3.2.37)

- Light output shall measure a minimum of **160 cd on-axis**;
- Light units shall be designed to operate from either an AC or DC source of 10V ±15%;
- Light units shall be rated at 68°F (20°C).

1. Light output (off-axis values) shall typically be as follows:

Minimum Luminous Intensity (cd) for LED Lamps

	30°L	*25°L*	*20°L*	*15°L*	*10°L*	*5°L*	*0°*	*5°R*	*10°R*	*15°R*	*20°R*	*25°R*	*30°R*
0°	3	3	5	13	51	128	160	128	51	13	5	3	3
5° D							128						
10° D							51						
15° D							13						
20° D							5						
30° D							3						

In 1999 AREMA took over leadership in setting standards. This organization noted the discrepancy between incandescent and LED light on-axis brightness requirements, noted that both types of lights appeared to work well, and decided to return to a ‘performance’ standard that specified the range of the lights in feet, as was done by AAR in 1966. The standard specified the visible distance of the signal across a horizontal beam pattern. However, the width of the beam was increased sharply over the 1966 requirements, and both a visibility requirement and beam pattern were described that do not ‘match up’ in the horizontal direction.

1999 AREMA Luminous Intensity & Distribution Standard (Part 3.2.35) Incandescent and LED Lamps

Visibility Requirements

Visible Distance (Feet) for 30-15 Lens (Front Light)

	15°L	10°L	5°L	0°	5°R	10°R	15°R
0°	500	1500	1500	1500	1500	1500	500

Visible Distance (Feet) for 70 Lens (Back Light)

	35°L	30°L	25°L	20°L	15°L	10°L	5°L	0°	5°R	10°R	15°R	20°R	25°R	30°R	35°R
0°	200	300	500	600	700	900	1300	1500	1300	900	700	600	500	300	200

Visible Distance (Feet) for 20-32 Lens (Cantilever Lane Light)

	10°L	5°L	0°	5°R	10°R
0°	1000	1500	1500	1500	1000

Beam Pattern

Note: there is some discrepancy between the visible distance requirement and the beam pattern description. For example, for the 30-15 Lens, the visible distance at 10° L/R should be the same as on-axis, but the beam pattern table indicates that the intensity at 10° L/R should be 31% of the on-axis intensity.

Percent of on-axis output – 30-15 Lens Front Light

	15°L	10°L	5°L	0°	5°R	10°R	15°R
0°	13	31	63	100	63	31	13
5° D				2			
10° D				2			
15° D				1			

Percent of on-axis output – 70 Lens Back Light

	30°L	25°L	20°L	15°L	10°L	5°L	0°	5°R	10°R	15°R	20°R	25°R	30°R
0°	1	2	13	21	33	67	100	67	33	21	13	2	1

Percent of on-axis output – 20-32 Lens Cantilever Lane Light

	10°L	5°L	0°	5°R	10°R
0°	31	63	100	63	31
5° D			3		
10° D			2		
15° D			1		
20° D			1		
30° D			0.3		

The AREMA standard also introduced the concept of a ‘universal’ lens with a circular beam, modelled after the beam produced by LED signal heads with no secondary lensing. The universal beam pattern is presumably intended to replace the above three beam patterns. No visibility range requirement is specified for the universal beam.

Percent of on-axis output – Universal Lens (based on horizontal and vertical axis deflection)

	30°L	*25°L*	*20°L*	*15°L*	*10°L*	*5°L*	*0°*	*5°R*	*10°R*	*15°R*	*20°R*	*25°R*	*30°R*
0°	2	4	13	21	33	80	100	80	33	21	13	4	2
5° D							80						
10° D							33						
15° D							21						
20° D							13						
30° D							2						

In 2002, the AREMA committee again addressed the photometric requirements for both incandescent and LED signal lights, with the following changes.

30-15 range requirements were changed, but not the percentage description of the beam pattern (e.g., at 10° horizontal deflection, the range requirement has dropped from 1500 to 469 ft.), and the vertical light requirements are specified both in percentage and in feet, with the two not agreeing (at 5° vertical deflection, percentage is 2% whereas range is reduced to 945 ft. or 63% of 1500 ft.).

20-32 range requirements have been changed (e.g., at 5° horizontal deflection, 1500 ft. has dropped to 945 ft.); the ranges in feet are identical to the 30:15, while the percentages are not.

70 on-axis range in feet has been dropped from 1500 to 1200 ft., percentages and ranges do not appear to have a logical relationship.

LED beam pattern is still circular, but the beam is considerably narrow (21% to 8% at 15°, 13% to 3% at 20°). The beam has also been described in feet, with the range in feet agreeing with the percentage of light output (but with no square function relationship). The range requirements and the percentage of light output do not appear to agree based on a normal square law relationship.

The full text of the 2002 photometric requirements is as follows:

2002: AREMA Luminous Intensity & Distribution Standard (Part 3.2.35) Incandescent and LED Lamps

Visibility Requirements

Visible Distance (Feet) for 30-15 Lens (Front Light)

	15°L	10°L	5°L	0°	5°R	10°R	15°R
0°	188	469	938	1500	938	469	188
5°				945			
10°				465			
15°				195			

Visible Distance (Feet) for 70 Lens (Back Light)

	35°L	30°L	25°L	20°L	15°L	10°L	5°L	0°	5°R	10°R	15°R	20°R	25°R	30°R	35°R
0°	13	13	31	188	313	500	1000	1200	1000	500	313	188	31	13	13

Visible Distance (Feet) for 20-32 Lens (Cantilever Lane Light)

	10°L	5°L	0°	5°R	10°R
0°	469	938	1500	938	469
5°			945		
10°			465		

Visible Distance (Feet) for LED Light

	35°L	30°L	25°L	20°L	15°L	10°L	5°L	0°	5°R	10°R	15°R	20°R	25°R	30°R	35°R
0°	30	30	30	45	120	480	1200	1500	1200	480	120	45	30	30	30
5°								1200							
10°								480							
15°								120							
20°								45							
30°								30							

Beam Pattern

Percent of on-axis output – 30-15 Lens Front Light

	15°L	10°L	5°L	0°	5°R	10°R	15°R
0°	13	31	63	100	63	31	13
5° D				2			
10° D				2			
15° D				1			

Percent of on-axis output – 70 Lens Back Light

	35°L	30°L	25°L	20°L	15°L	10°L	5°L	0°	5°R	10°R	15°R	20°R	25°R	30°R	35°R
0°	1	1	2	13	21	33	67	100	67	33	21	13	2	1	1

Percent of on-axis output – 20-32 Lens Cantilever Lane Light

	10°L	5°L	0°	5°R	10°R
0°	31	63	100	63	31
5° D			3		
10° D			2		
15° D			1		
20° D			1		
30° D			0.3		

Percent of on-axis output – LED Light

	$35^O L$	$30^O L$	$25^O L$	$20^O L$	$15^O L$	$10^O L$	$5^O L$	0^O	$5^O R$	$10^O R$	$15^O R$	$20^O R$	$25^O R$	$30^O R$	$35^O R$
0^O	2	2	2	3	8	33	80	100	80	33	8	3	2	2	2
$5^O D$								80							
$10^O D$								33							
$15^O D$								8							
$20^O D$								3							
$30^O D$								2							

2.1 The Need for this Standard

Traditionally Transport Canada has relied on AAR and AREMA to set the standards for highway-railway crossing lights. However, in the case of the LED technology, Transport Canada is concerned because of the following:

- The difference between the LED and the incandescent light standard by AAR (which can be as high as 1600 cd versus 160 cd),
- AREMA's decision to switch back to a range requirement in feet, which is difficult to verify, and
- The changing beam pattern requirements in the AREMA standard.

Transport Canada has taken the position that, in Canada, there must be a measurable, verifiable, and justifiable standard in place before LED technology is implemented on Canadian highway-railway crossings. This project is tasked with the development of that standard.

3. CURRENT STATUS OF PHOTOMETRIC SPECIFICATIONS FOR TRAFFIC LIGHTS

3.1 Institute of Transportation Engineers (ITE) Standard

Leadership in the specification of highway traffic lights rests with the Institute of Transportation Engineers in North America. The intensity and beam pattern of incandescent traffic lights is specified as follows:

ITE Luminous Intensity & Distribution Standard for Traffic Signals: ***Incandescent*** Signals (1998, Part 2.11.04)

Minimum Luminous Intensity (cd) – 8 in. Incandescent Traffic Light

	Horizontal Angle Left (L) and Right (R)												
	27.5°L	*22.5°L*	*17.5°L*	*12.5°L*	*7.5°L*	*2.5°L*	*0°*	*2.5°R*	*7.5°R*	*12.5°R*	*17.5°R*	*22.5°R*	*27.5°R*
0°													
2.5° D			29	67	114	157		157	114	67	29		
7.5° D	12	21	48	76	105	119		119	105	76	48	21	12
12.5° D	10	14	24	33	38	43		43	38	33	24	14	10
17.5° D	5	7	10	12	17	19		19	17	12	10	7	5

Minimum Luminous Intensity (cd) – 12 in. Incandescent Traffic Signal

	Horizontal Angle - Degrees Left (L) and Right (R)												
	27.5°L	*22.5°L*	*17.5°L*	*12.5°L*	*7.5°L*	*2.5°L*	*0°*	*2.5°R*	*7.5°R*	*12.5°R*	*17.5°R*	*22.5°R*	*27.5°R*
0°													
2.5° D			90	166	295	399		399	295	166	90		
7.5° D	19	45	105	171	238	266		266	238	171	105	45	19
12.5° D	19	26	40	52	57	59		59	57	52	40	26	19
17.5° D	19	24	26	26	26	26		26	26	26	26	24	19

This standard for incandescent traffic lights is an initial standard and does not require that the signals continue to meet the performance requirements when in service. In developing the standard for LED signals, the ITE committee lowered the standard by 15% but required that the LED specification be maintained over temperature and over the warranty period (Sullivan et al., 1997).

ITE Luminous Intensity & Distribution Purchase Standard for Traffic Signals: *LED* Signals (1998, Part 2a.4.1) (end of 3 year warranty period and at 74°C)

Minimum Requirements

8 in. LED Traffic Signal (cd)

	Horizontal Angle Left (L) and Right (R)												
	27.5°L	22.5°L	17.5°L	12.5°L	7.5°L	2.5°L	0°	2.5°R	7.5°R	12.5°R	17.5°R	22.5°R	27.5°R
0°													
2.5° D			25	57	97	133		133	97	57	25		
7.5° D	10	18	41	65	89	101		101	89	65	41	18	10
12.5° D	9	12	20	28	32	37		37	32	28	20	12	9
17.5° D	4	6	9	10	14	16		16	14	10	9	6	4

12 in. LED Traffic Signal (cd)

	Horizontal Angle Left (L) and Right (R)												
	27.5°L	22.5°L	17.5°L	12.5°L	7.5°L	2.5°L	0°	2.5°R	7.5°R	12.5°R	17.5°R	22.5°R	27.5°R
0°													
2.5° D			77	141	251	339		339	251	141	77		
7.5° D	16	38	89	145	202	226		226	202	145	89	38	16
12.5° D	16	22	34	44	48	50		50	48	44	34	22	16
17.5° D	16	20	22	22	22	22		22	22	22	22	20	16

The wording in the standard regarding the maintenance of this light output over time reads as follows: "The maintained minimum luminous intensity values for the LED traffic signal modules throughout the warranty period, under the operating conditions defined in Sections 3.3 (-40°C to 74 C) and 5.2.1 (voltage range of 80 to 135 V), and at the end of the warranty period, shall be not less than the values shown …."

The standard also specifies the maximum intensity of the LED signal, requiring that the luminous intensity not exceed 800 cd.

Bullough et al. (1999) studied the effect of lowering the standard by 15%, as well as the effect of the colour of the LED signals. After comparing the incandescent technology operating at the ITE required output of 399 cd with the LED technology operating the required output of 339 cd, they concluded:

- The difference between the mean reaction times of drivers was not statistically significant
- There were no statistically significant differences in terms of missed signals, colour identification or their brightness and conspicuity ratings.

Table 1 – Predicted Changes in Mean Reaction Time, Missed Signals, Rated Brightness, and Rated Conspicuity as Consequence of Reducing Luminance of LED signals by 15% as in ITE Specifications (part of the table)

Measure	Red LED
Percentage change in reaction time	+2.4%
Percentage change in missed signals	from 0.7% to 0.8%
Change in rated brightness (1=very dark, 10=very bright)	from 6.34 to 6.03
Change in rated conspicuity (1=invisible, 10=very conspicuous)	from 6.66 to 6.32

The ITE Specifications for both incandescent and LED signals have most recently been reviewed by the National Co-operative Highway Research Project, Transportation Research Board, National Research Council Project 5-15: Visibility Performance Requirements for Vehicular Traffic Signals. This report concludes by recommending that the standards for high-speed road applications should be increased to the level suggested by Hulscher (1975): 600 cd with backboards. This is the same standard used by Australia (see section 3.3). The ITE has taken issue with the methodology and conclusions of this report, and it does not appear likely that any change in the ITE standard will occur in the near term (Cheeks, 2002).

3.2 European Standard

3.2.1 Traffic Control Equipment – Signal Head (EN 12368:2000)

In Europe, the luminous intensity of signal lights, for both 200 mm and 300 mm roundels, are as specified in Table 2. The table also specifies a maximum light output.

Table 2 – Luminous Intensities (I) for Red, Yellow, and Green Signal Lights in the Reference Axis

Performance Level	1	2	3
I_{min}	100 cd	200 cd	400 cd
I_{max} *class 1* I_{max} *class 2*	400 cd 1100 cd	800 cd 2000 cd	1000 cd 2500 cd

The standard specifies four angular distributions of luminous intensities for signal lights. The user may choose between an extra wide, wide, medium and narrow beam signal to obtain a good recognition of the signal for short distances in urban areas and for long distances in rural areas. These angular distributions are specified as minimum luminous intensities and are expressed as percentage values. Table 3 represents the wide beam signal, used in our comparison, since this beam pattern corresponds to the universal beam pattern and is applicable to all of the intensities in Table 2.

Table 3 – Wide Beam Signal (Type W)

	Horizontal Angle Left (L) and Right (R)												
	30° L	***20° L***	***15° L***	***10° L***	***5° L***	***2.5° L***	***0°***	***2.5° R***	***5° R***	***10° R***	***15° R***	***20° R***	***30° R***
0°	1	3	-	55	85	-	100	-	85	55	-	3	1
1.5° D	-	-	-	-	-	-	-	-	-	-	-	-	-
3° D	-	-	-	-	75	-	80	-	75	-	-	-	-
5° D	-	-	-	35	-	-	60	-	-	35	-	-	-
10° D	-	8	-	-	-	-	30	-	-	-	-	8	-
20° D	2	-	-	-	-	-	2	-	-	-	-	-	2

– means no specific values are required

This standard is an initial standard, but a degradation of not more than 20% is allowed. The wording is as follows:

“The optical performance of signal heads in use is a function of lens soiling, mirror soiling and a decrease of luminous flux from the lamp. To maintain the performance of the signal heads during service, it is important to ensure that after lamp replacement and cleaning of lens and mirror, the light output is restored to as near 100% as possible and never lower than 80% of the certified specified performance(s).”

3.3 Australian Standard

3.3.1 Traffic Signal Lanterns (AS 2144 – 1995)

Australia pioneered much of early research on photometric requirements for traffic lights, and has gone its own way in defining standards. The Australian standard for traffic lights on high-speed roads is 600 cd, with a somewhat narrower beam than used in North America. The standard requires that the luminous intensity be not less than the values in Table 4.

Table 4 – Distribution of Luminous Intensity from Extended Range Lanterns

	Horizontal Angle Left (L) and Right (R)														
	25° L	***20° L***	***15° L***	***10° L***	***7.5° L***	***5° L***	***2.5° L***	***0°***	***2.5° R***	***5° R***	***7.5° R***	***10° R***	***15° R***	***20° R***	***25° R***
0°	-	-	-	100	-	200	600	600	600	200	-	100	-	-	-
1.5° D	-	-	-	-	-	-	-	600	-	-	-	-	-	-	-
3° D	-	-	-	-	100	-	-	200	-	-	100	-	-	-	-
5° D	-	15	-	-	-	-	-	100	-	-	-	-	-	15	-
7.5° D	-	-	25	-	-	-	-	-	-	-	-	-	25	-	-
10° D	-	-	-	-	-	-	-	25	-	-	-	-	-	-	-
15° D	15	-	-	-	-	-	-	-	-	-	-	-	-	-	15
20° D	--	-	-	-	-	-	-	15	-	-	-	-	-	-	-

The Australian standard is an initial standard applying to “new lanterns in clean condition”. The standard states that the specified values include a “nominal allowance for the reduction in light output which will occur between periodic maintenance operations. This reduction in light output is the result of aging of the lamp and soiling of the optical surfaces of the lantern under average operating conditions.”

3.4 Comparison of Different Traffic Standards

Figure 3 is an approximate comparison of the on-axis beam pattern called for by the ITE North American standard, the European standard, and the Australian standard. The comparison is approximate since the ITE standard does not specify the on-axis intensities: no intensities are specified until 2.5 degrees down. Remember that the ITE standard is a 'maintained' standard, the European standard allows a 20% reduction in use, and the Australian standard includes a 'nominal' allowance for reduction in light output when the signal is installed.

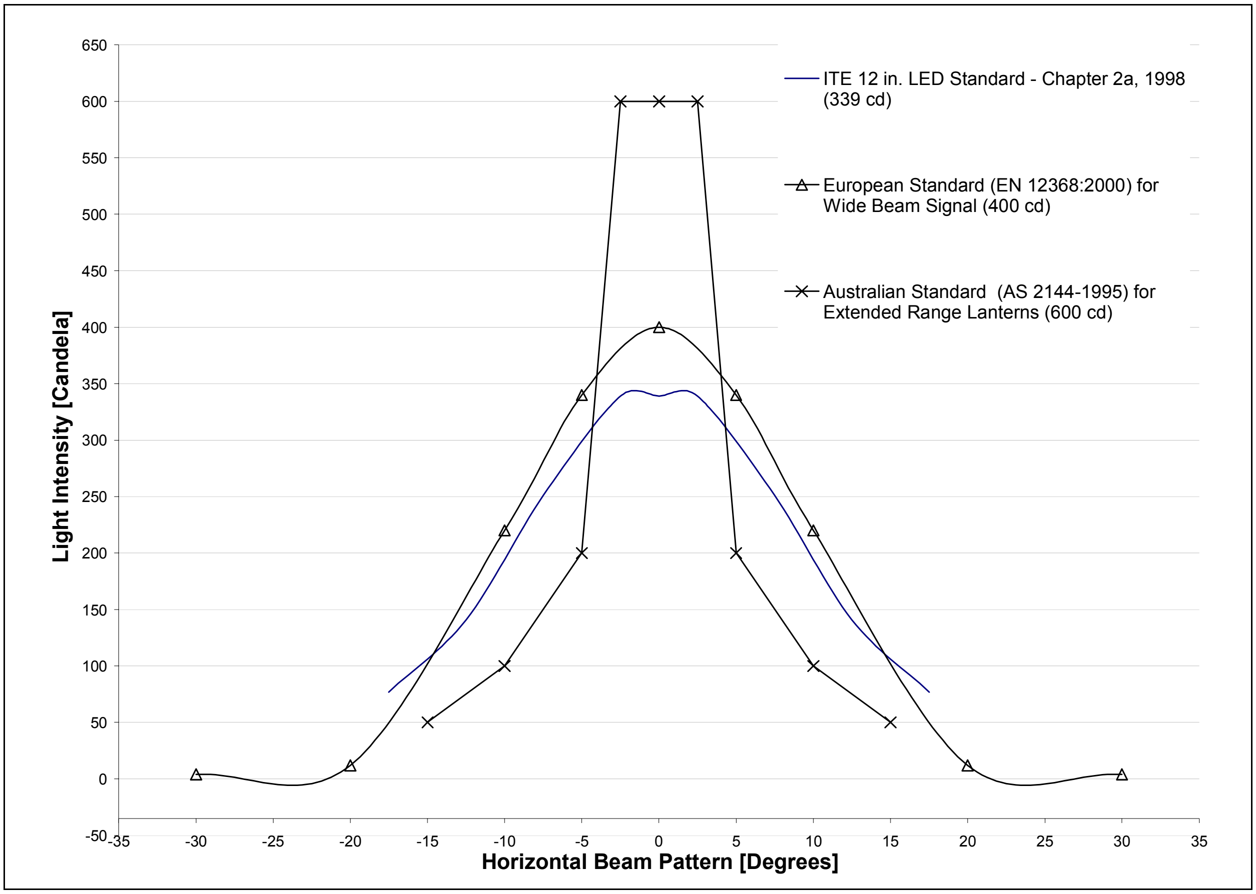


Figure 3 Comparison of On-Axis Beam Pattern for Different Traffic Standards (ITE starts at -2.5°)

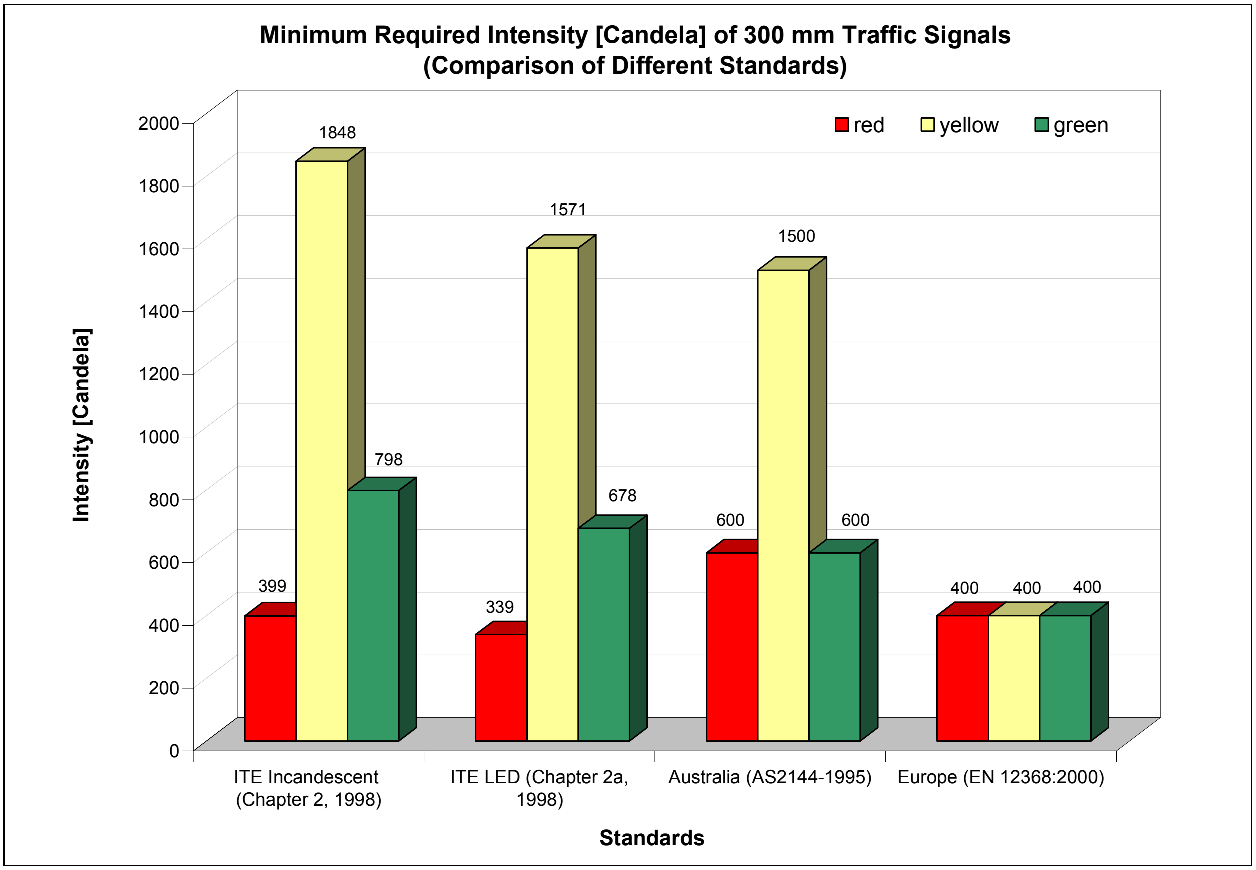


Figure 4 Comparison of Standards in Different Countries (300 mm)

3.5 Conclusion re Current Status of Standards

The standards for red traffic lights on high-speed roads do not differ greatly around the world, particularly when the full beam pattern and the wording regarding maintenance of the standard are considered. In North America, the ITE standard for red LED traffic lights has been accepted by all states and provinces, and the adoption of LED traffic lights is proceeding rapidly across the continent (Balthazar, 2001).

4. STATUS OF LED TECHNOLOGY

One of the problems in producing a standard for LED signal modules is the rate of improvement in LED technology. Ten years ago LEDs were only in use as red indicator lights on circuit boards, dashboards, etc. The production of light from LEDs has advanced remarkably since then. Virtually all colours can now be produced, and the brightness has increased so dramatically that it is now approaching a dangerous level if viewed directly.

The best red LEDs manufactured in laboratories in 1970 produced about 1 lm/W. Their efficiency has increased exponentially, and the best red LEDs being produced in laboratories are now approaching 45 lm/W (Craford et al., 2001). Typical red LEDs that are in commercial production are now 20 lm/W.

Incandescent bulbs produce about 15-20 lumens of white light per watt of electricity consumed. Once a red filter is added, about two-thirds of the light is filtered out. As a result, red LEDs are at least three times as efficient at producing red light from electricity as an incandescent bulb. Furthermore, the red light produced is 'purer' and more penetrating.

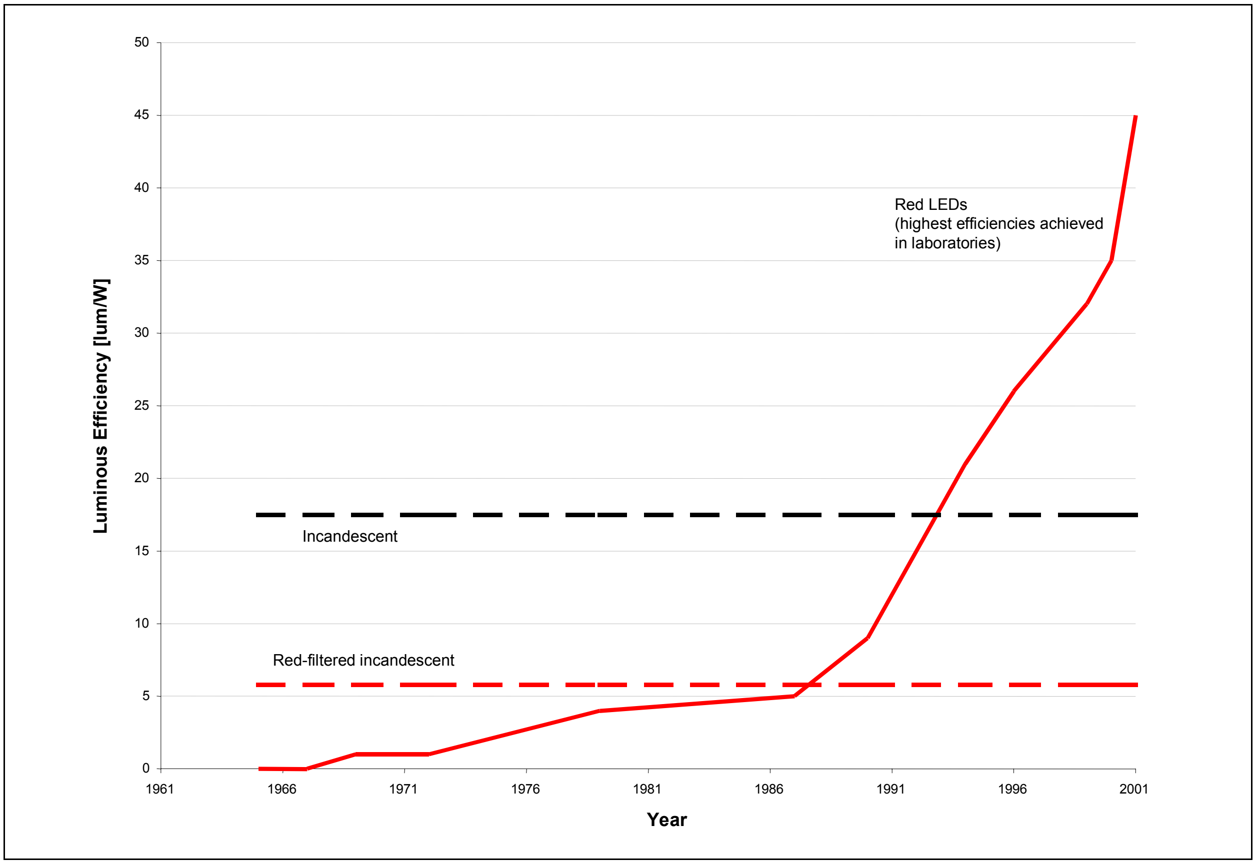


Figure 5 Comparison of Luminous Efficiency of Red LEDs and Incandescent Bulbs (Craford et al., 2001)

Besides efficiency in producing light, LEDs also last incomparably longer than incandescent light sources, and are impervious to vibration and shock. Figure 6 shows the solid-state, potted construction of an LED. Table 5 shows the mean time between failure (MTBF) for LEDs. Even assuming the highest expected ambient temperature was experienced for the entire life of the LED (75°C), the MTBF would be over one million hours. The typical MTBF for incandescent bulbs ranges from 1000 hours to 5000 hours, so the LEDs are incomparably superior in terms of their projected lifetime.

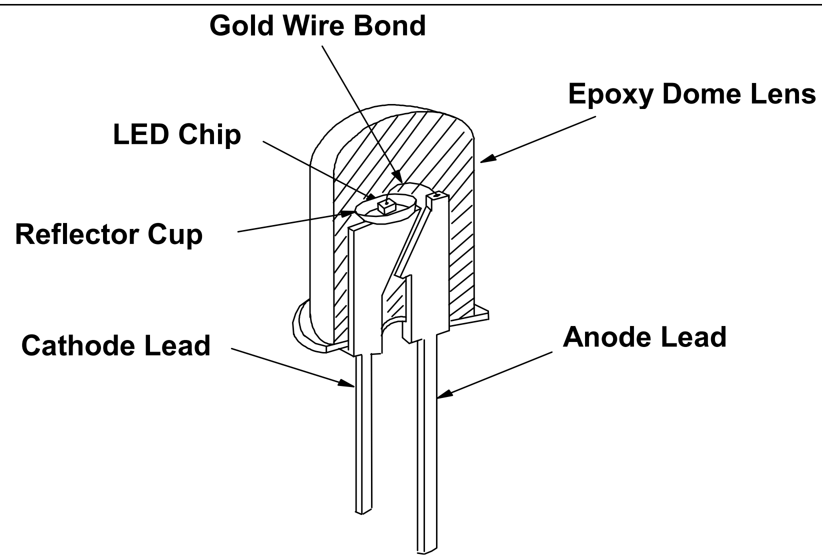


Figure 6 Typical LED Construction

Table 5 – MTBF and Failure Rate for Precision Optical Performance AlInGaP LED T-1 3/4 Plastic Lamps (Agilent Application Brief I-004)

Ambient Operating Temperature [°C (°F)]	LED Temperature [°C (°F)]	Mean Time Between Failure (MTBF) [hours]	Device Failure Rate λ [%/1000 heures]
85 (185)	103 (217)	848,000	0.188
75 (167)	93 (199)	1,220,000	0.082
65 (149)	83 (181)	1,791,000	0.056
55 (131)	73 (163)	2,688,000	0.037
45 (113)	63 (145)	4,133,000	0.024
35 (95)	53 (127)	6,525,000	0.015
25 (77)	43 (109)	10,701,000	0.009
15 (59)	33 (91)	17,978,000	0.006
5 (41)	23 (73)	30,922,000	0.003

Since LEDs last so long, degradation with time is a concern that must be addressed. Light output from LEDs declines with use, but the rate of degradation is exceedingly slow. The logarithmic graph in Figure 7 shows the projected rate of decline. This graph does not have any actual data after 20,000 hours of use, since LEDs using AlInGaP technology have not been in existence for much longer than that.

The rate of degradation depends on the current used to drive the LEDs (see Figure 8). With the existing LED technology, the maximum continuous drive current that should be used is 30 mA. For the highway-railway grade crossing application, the typical usage that might be expected of an LED signal module is about 300 hours per year. 10,000 hours of use would provide approximately 15 years life for an LED light source, which is more than the housings, seals and other components of the warning system could be expected to last. The decrease in LED light output over 10,000 hours of use, at a drive current of 30 mA, would result in a maximum degradation in light output over time of 20%.

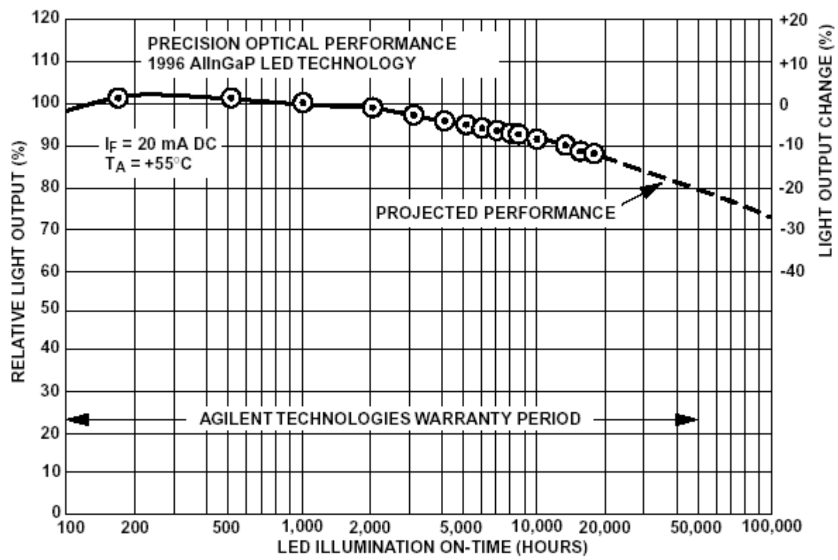


Figure 7 Projected Average Light Output Degradation Performance for Precision Optical Performance AlInGaP LED Lamps, Based on 16,000 Hours of High Temperature Operating Life (HTOL) Data (Agilent Technologies, Application Brief I-018, 1999)

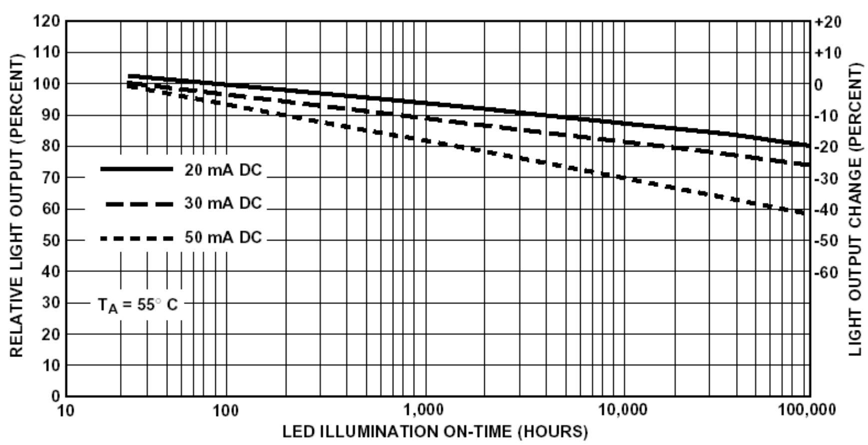


Figure 8 Projected Long-Term Output Degradation for Various DC Drive Currents (Agilent Technologies, Application Brief I-024, 1999)

In considering the issues regarding using LEDs as a light source for the highway-railway light application, it is important to remember that it is the overall system reliability that is the important factor. Many LEDs must be soldered together to make an LED array, and drive circuitry is required to power the LEDs. The weakest link in this system is the electronic driver circuitry (see Figure 9). If extremely long life and high reliability are essential, then it is prudent to have redundancy in the drive circuitry so that if a component fails, there is a backup circuit to drive the LEDs.

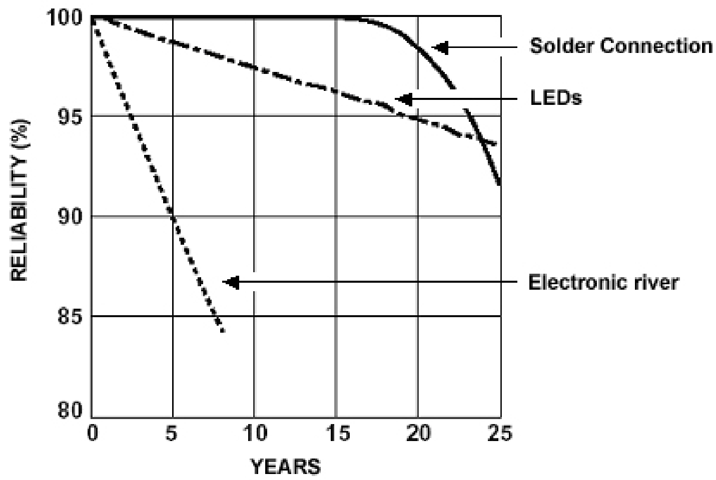


Figure 9 Reliability of Traffic Signal Components (LumiLeds, Application Brief SO1, 2000)

A final important consideration in using LEDs for signal lights is their performance over temperature. Whereas incandescent lights produce approximately the same light output over a broad range of temperatures, the current LED technology is less efficient at high temperatures. The decrease in light output with increasing temperature is significant – nearly 1% decrease in light output for each degree of temperature us above 20°C (Figure 10). Specifications for LED signal lights need to ensure that the light output is maintained over the temperatures likely to be encountered in real operation.

Incandescent bulbs did not have particularly long life spans, and did not vary much with temperature. LED lights have very long life, and do have significant temperature issues. For this reason, it is important to specify end-of-life requirements and temperature range performance for LED signal modules. The following provide some idea of the buffer required to allow for degradation over time and temperature.

- Testing should be based on the minimum light output requirements as called for in ITE Purchase Specification, plus 40% to take into account normal degradation of current LED technology (i.e., approximately 500 cd) (CN Alignment Criteria - Test Report, 1997).
- Some issues that will affect the intensity: a 1°C change in temperature will result in approximately 1% change in intensity (approximately 30-40% reduction at 74°C) (Durgin, 1998).

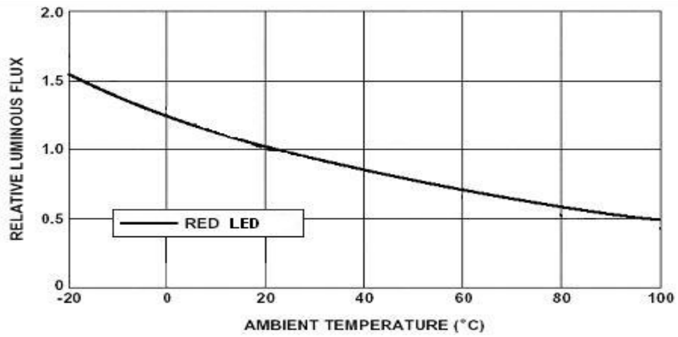


Figure 10 Luminous Flux vs. Ambient Temperature for a Typical Red AlInGaP LED when Operated at a Constant Current (LumiLeds, Application Note 1149-4, 2000).

4.1 Luminous Intensity Advantages of LEDs

Typically railway lights have used 18 W incandescent bulbs running at a nominal 10 V. Based on the luminous efficiency data, the following comparison shows the advantage of switching from incandescent bulbs to LEDs as a light source:

Comparison of Red Light Output from Incandescent Bulbs and LEDs

Incandescent bulbs:

- Typically have an average luminous efficiency of 15-20 lm/W
- Assume average of 17.5 lm/W
- Red filtering reduces this to about a third, or 5.8 lm/W
- Assume an 18 W bulb is used
- The incandescent bulb produces 5.8 x 18 = 104 lm while consuming 1.8 A at 10 V.

Red LEDs

Commercially available LEDs in year 2000 (last year for which such data is available) typically had a luminous efficiency of 15-20 lm/ W (Agilent Technologies, 2000) (*there are continual improvements to this efficiency)*

- Assume 20 lm/W average in 2001
- LEDs do not require filtering, but do require a power supply, which may have efficiency losses of about 15%
- Assume 17 lm/W after allowing for power supply losses
- Assume LED signal modules are set to use the same power consumption as incandescent bulbs: 1.8 A at 10 V = 18 W
- This power consumption will produce 18 x 17 = 306 lm, or about three times the light output of incandescent bulbs while drawing the same current draw.

Conclusion

LEDs can produce red light about three times as efficiently as incandescent bulbs.

4.2 Beam Patterns of LED Lights

Incandescent bulbs have been in use for over a century, and there are lenses for almost every conceivable beam pattern. Unfortunately, placing an LED signal module (an array of LEDs) behind a lens designed for an incandescent light often does not work. The LED array has many light sources, as opposed to the single filament at the centre of an incandescent bulb. It is, for example, not practical to place an LED array at the focal point of a parabolic mirror and a single LED would not produce sufficient light output.

Each individual LED is encapsulated in epoxy that serves as a lens to focus the light produced. The pattern produced is a cone of light, typically with a beam angle ranging from 7° to 30°. An array of LEDs that are aligned in the same direction produces the same cone of light as an individual LED, but with higher intensity.

In order to produce beam patterns other than this conical pattern, a lens is required. This is often referred to as a secondary lens. Lensing a group of LEDs to produce a given beam pattern requires that a lens element be placed in front of each LED. These lenses require optical design, a new injection mould and a start-up cost, so there is certain inertia to producing new lenses for each LED array. The secondary lensing also adds somewhat to the complexity and cost of the final product.

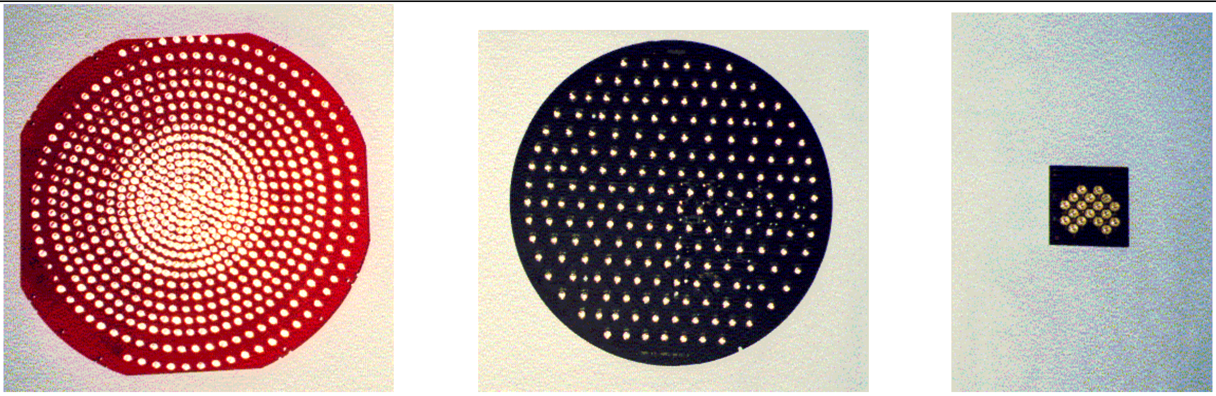
Since existing incandescent lenses do not work for LED arrays, now is the time to re-think the beam pattern requirements for highway-railway crossing lights to ensure that they are optimized for the purpose for which they are intended. The beam patterns should also be as universal as possible to ensure that the economics of scale induce manufacturers to produce the required lenses.

Simply requiring that the beam be the same as traditional incandescent lights is not wise. Incandescent beam patterns were not ideal in terms of meeting the needs of drivers. Instead, they were more an expression of what could be achieved with the technology. The narrow beam pattern that they produce in the vertical direction requires focusing and alignment precision to be effective. Now that a new technology allows broader beam patterns, driver safety should be the determinant of the beam pattern.

4.3 Use of LEDs in Traffic Lights

In the highway market, there are now hundreds of thousands of red LED traffic light signal modules in use. Adoption of the technology is moving very quickly driven by energy savings and by the reduction of maintenance costs.

There are a number of manufacturers addressing the market in North America. The design strategies vary quite dramatically, with large variations in the number of LEDs used, the lensing arrangements, the power supply characteristics, and the physical structure of the modules. Figure 11 shows the variation in LED arrangements, and Figure 12 is an example of how the LEDs are mounted inside a module behind a secondary lens (the primary lens is the LED itself). All traffic lights use secondary lenses to modify the beam pattern of the LEDs to meet the ITE traffic light standard.



600 LEDs | 196 LEDs | 18 High Flux LEDs

Figure 11 Examples of LED Arrangements in Traffic Lights

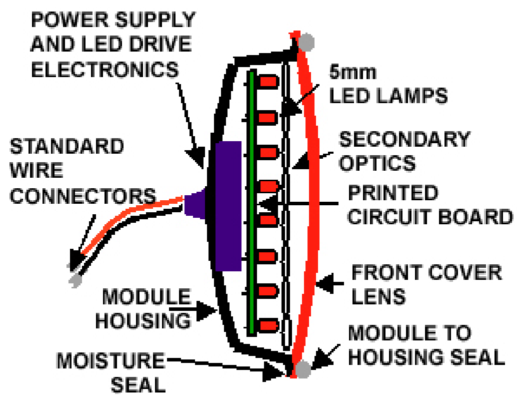


Figure 12 Example of Traffic Light Module

The energy and maintenance savings are so compelling for the traffic light application that red traffic lights are likely to be universally adopted over the next decade. Several jurisdictions are providing incentives and subsidies to municipalities to encourage adoption of the technology (Quesnel, 2002).

4.4 Practical Experience with LED Signal Modules in Grade Crossings

The use of LEDs for railway crossing signals has moved much more slowly than for traffic lights. Some of the key differences in the two markets are:

- energy savings are less compelling, since crossing lights have a low duty cycle of use each day;
- the market is much smaller and more specialized;
- the power supplies required are more complicated, since they must operate on both low voltage AC and DC;
- there has been widespread uncertainty about the standard that the signal modules must meet.

There are currently about 20,000 LED lights in use at railway crossings in the U.S. Obviously, this constitutes a major experiment in the use of these types of lights, and the daily reliance on these lights is a source of data that cannot be ignored as we set a standard in Canada.

Most of the LED signal modules in use in the U.S. were designed to meet the original AAR standard of 160 cd. Many of the LED signal modules in use do not use a secondary lens and produce a circular cone of light that is as broad in the vertical direction as it is in the horizontal direction.

The evidence from the field use of these LED signal modules is that they produce a beam that is sufficiently ‘universal’ to be suitable for any of the three main uses of signals (front, back and lane marking). They do not require focusing, so alignment is straightforward. Maintenance is much reduced because the LED modules have proved to be more durable (Sharkey, 2001-2002).

5. HUMAN FACTORS

The introduction of LEDs for key safety lighting applications raised concerns because of possible differences in human perception of the more monochromatic light emitted by LEDs. Red LEDs produce a narrower range of wavelengths than a filtered incandescent light bulb. The current LED technology, AlInGaP, produces red light with wavelengths in the range of 640 nm +/- 20 nm. Incandescent bulbs produce white light of all frequencies, which is then filtered by a red lens to remove the higher frequency wavelengths. The lens leaves behind all of the red spectrum including longer wavelengths out to 700 nm (the limit of human eye response) and beyond into the infrared region.

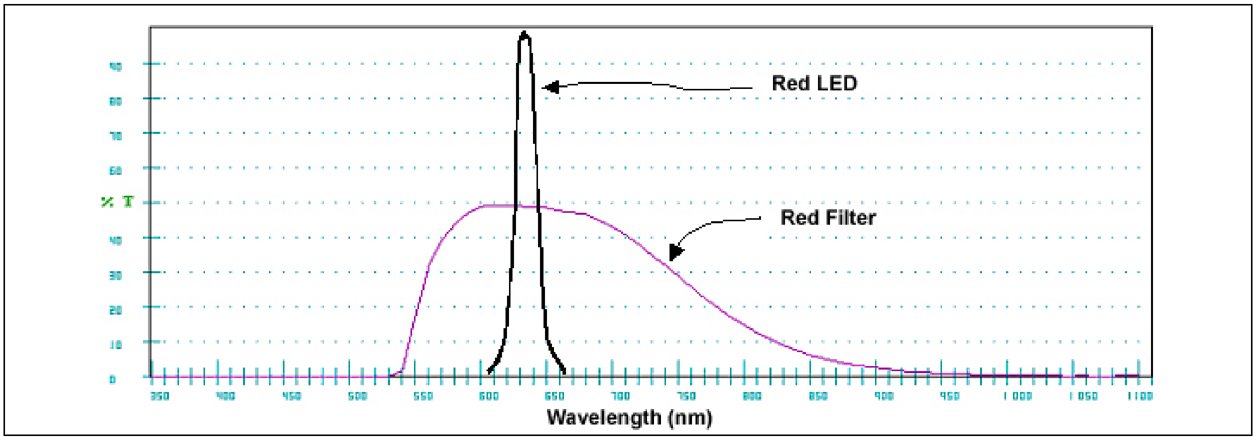


Figure 13 Spectrum of a Red LED (AlInGaP) Compared with a Red-Filtered Incandescent Light Source

The following sections review the various human factors that may impact on the conspicuity of LED signal lights and may be relevant for setting the performance standard for LED signals.

5.1 Colour-Deficient Individuals

Drivers with colour-deficient vision are an obvious concern whenever there is a change in light characteristics of warning/hazard lights. By far the most common problem amongst those with colour-deficient vision is red-green colour deficiency, which occurs in approximately 8% of men and 0.4% of women (Eklund, 1999). The question that concerns us here is whether red LED signals are likely to be less conspicuous than incandescent signals for colour-deficient individuals.

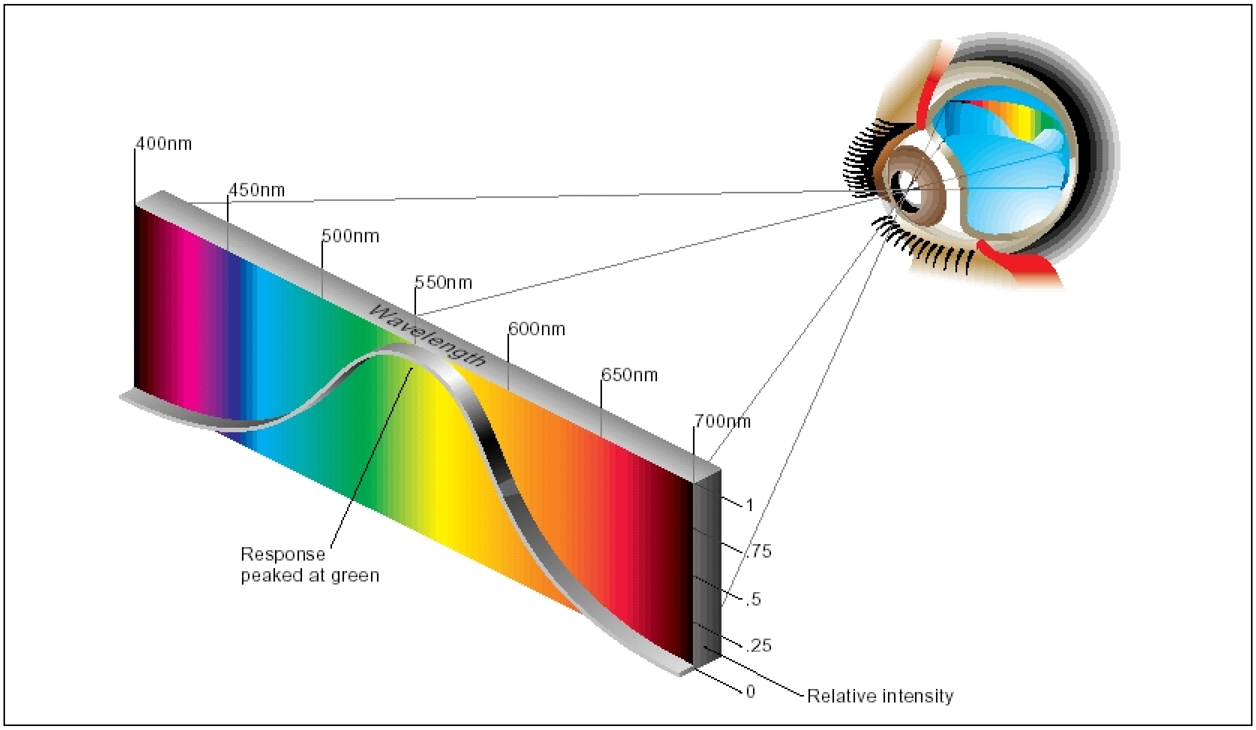


Figure 14 The Relative Eye Sensitivity of an Assumed "Standard Observer" at Different Wavelengths for Normal Levels of Illumination (CIE Photopic Curve) [Silicon Graphics Computer Systems: http://www.sgi.com/products/legacy/displays.html]

The terms used in describing colour vision are:

- trichromats, who can see all three primary colours,
- dichromats, who can see only two of the primary colours, and
- monochromats, who see only black and white.

The colour-deficient conditions that are common enough to be significant, and that are related to the perception of red signals, are one type of anomalous trichromat (protanomaly) and two subclasses of dichromats *(*protanopia and deuteranopia*)* (see Table 6). People who have these types of anomalous colour vision have problems distinguishing red from other colours, detecting red lights (whatever colour they might match it with), or both.

Protanomalous trichromats exhibit a shift in the red region of the spectrum, which can result in red-brown confusions and some tendency to be less sensitive to red light than normal trichromats. They are said to be "red weak". However, they do not appear to be any more likely to have problems with the narrower LED spectrum than with the broader incandescent spectrum, since the shift just results in a different perceived colour in both cases. The shading difference, if any, between the two types of lights would still not preclude the observer from seeing the flashing lights and realizing that they were warning lights, since they would not be confused with other colours.

All of those with colour vision defects characterized as dichromats are missing or do not exhibit the characteristic functioning of one of the three cone types, and cannot see one of the basic colours. The two types that do not have sensitivity to red are protanopia and deuteranopia. Dichromats are essentially incapable of discriminations among wavelengths above 540 nm. For example, protanopes match spectral red to very dim levels of spectral yellow. They also exhibit a loss of sensitivity to long wavelengths (Pezoldt et al., 1997). For these dichromats, red LED signals will tend to be more conspicuous than incandescent signals since it is the longest wavelengths that they find the most problematic.

Table 6 – Classification and Frequency of Occurrence of Inherited Colour Vision Systems (Pezoldt et al.,1997)

Designation	Discriminations Possible	Percentage of Population	
		Male	Female
Normal thichromats	Light-dark Yellow-blue Red-green	**92.0**	**99.6**
Anomalous trichromats		**5.9**	**0.4**
Protanomaly	Light-dark Yellow-blue Red-green (red weak)	1.0	0.02
Deuteranomaly	Light-dark Yellow-blue Red-green (green weak)	4.9	0.38
Tritanomaly	Light-dark Yellow-blue (blue weak) Red-green	0.0001	0.00
Dichromats		**2.1**	**0.03**
Protanopia	Light-dark Yellow-blue	1.0	0.02
Deuteranopia	Light-dark Yellow-blue	1.1	0.01
Tritanopia	Light-dark Red-green	0.0001	0.00
Tetartanopia	Light-dark Red-green	0.0001	0.00
Monochromats	Light-dark	**0.003**	**0.002**
All Abnormal Systems		**8.00**	**0.43**

Cole and Brown (1966) compared the response of observers with normal colour vision to that of a group of protanopes. They concluded that protanopic drivers require a signal of about four times the luminance required for normal drivers, an intensity of at least 600 cd for an 8 in. signal. However, they concluded that a signal of optimum luminance for normal drivers [160 cd to 260 cd] is likely to be seen by protanopes with some certainty even though their response times may, on the average, be longer.

Whillans and Allen (1992), in a review of the literature, have concluded that colour vision deficient (CVD) observers take from 42 to 98% more time than normal viewers to respond to colour signals. They also point out that many tinted lenses can affect drivers with normal vision by rendering their visual performance similar to CVDs, which brings us to our next topic.

5.2 Sunglasses

When LED traffic lights were first introduced, some drivers reported that their sunglasses made yellow LED lights difficult to see. The problem is less acute with red signals, presumably since most sunglasses are designed to reduce the yellow portion of the spectrum associated with sun glare, not the red portion of the spectrum. Nevertheless, according to Clark (1968), the lenses of some of the sunglasses used in his experiments with incandescent traffic signals were coloured to the extent that they significantly altered the contrast of a red signal against the sky background.

Cohn et al. (1996) specifically examined the issue of sunglasses and LED signal perception. Based on a limited number of tests, numerical integration was used to predict that “the usability factor” of red AlInGaP LED lamps, for an observer wearing sunglasses, would decrease by about 8% from that determined for an observer without sunglasses. In tests comparing red LED and incandescent signals, the differences in conspicuity between the two types of light sources for observers wearing sunglasses were not statistically significant.

5.3 Aging Eye

On the issue of the aging eye, the work of Fisher is usually quoted. Fisher (1969) reported that as a person ages, the ocular media yellows, which has the effect of enhancing the contrast between a red signal and a sky background. However, he noted that effect is more than offset by increasing light scatter within the eye, which diminishes contrast. He concluded that older drivers need increased levels of signal luminance and contrast in certain situations to perceive traffic signals as efficiently as a 20- to 25-year old.

Fisher (1969) reported that as a person ages, the contrast (ratio between the signal and a sky background) needs to be increased to ensure reliability of perception. At age 50, the contrast requirements are 1.5 times that of a young person, while at 70 the factor is 3. These factors are slightly less for the red and yellow signal, and slightly more for green ones.

An extensive study of the needs and safety of aging drivers was initiated recently by the U.S. Federal Highway Administration. The literature review includes a summary of studies conducted on the aging eye. Staplin et al. (1997) conclude that “driver age has not been studied in the context of traffic signal recognition; however, with regard to traffic signal brightness, it appears that the aged have reduced levels of sensitivity to intensity and contrast, but not to colour.”

These results imply that older drivers will not have any difficulty with the colour of an LED signal, since their colour perception does not degrade. They require strong contrast, and in general LED lights can offer more intensity and therefore stronger contrast than incandescent lights.

5.4 Sun Phantom

Sun phantom refers to the phenomenon of sunlight shining into a signal and reflecting back out to give the appearance that the signal is switched on. This may produce confusion for the motorist unless the luminous intensity of the real light signal is considerably greater than the intensity of any false signal. Recommendations on the acceptable minimum ratio of the intensities of the real and false signals vary from 12:1 (Fisher, 1971) to 15:1 (CIE Pub. No. 79, 1988).

Data in a study by Fisher and Millard (1971) suggests that elimination of sun phantom is a problem because most devices designed to restrict the sun phantom effect (e.g., visors, louvres, etc.) also limit beam intensity. Simple external cowls and adequate beam intensity appear to be the best solutions.

Incandescent railway signals have a parabolic reflector behind the bulb, so sunlight entering the signal can be reflected back sufficiently to illuminate the lens. LED signals do not use a reflector and so offer the potential to reduce the sun phantom effect. Also, LED signals do not need a coloured lens, so if the sun phantom effect is a problem in a certain area, it can be eliminated by using a clear lens instead of a red lens. Cohn et al. (1998) conducted a field experiment to compare the phantom effect with LED and incandescent lights, and concluded that “it was easy to distinguish when the red light was on under sun phantom conditions for both incandescent and LED lamps, but the LED actually had a strong advantage because its lens reflects much less of the sun’s light back at the observer.” They were unable to repeat the experiment in the laboratory but did determine “that the light reflected from the incandescent fixture was 50% greater than that from the lens of the LED device.”

5.5 Fog

With regard to the issue of whether LED signals will perform better or worse in poor visibility conditions such as fog, a literature review conducted in 1997 (NCHRP 5-15) concluded that “no research has directly addressed intensity requirements under adverse weather conditions.”

Cohn et al. (1998) attempted two experiments using artificial fog to compare LED and incandescent signals in the field. They found it difficult to maintain constant fog conditions, and were concerned about the possible differences between their ‘artificial fog’ and real fog conditions, but they concluded that there was no statistical difference between the fog and no-fog comparison of the two types of signals.

Based on physical principles, it is unlikely that the relatively minor difference between the wavelengths of red incandescent signals and LED signals would result in any significant difference in the scattering or absorption of light from the two types of signals in fog.

A key advantage that LED signal modules offer in fog situations is a broader beam. Since a driver is unlikely to be able to see the signal light at the normal alignment distance, the intensity of the signal light on closer approach to the crossing can be very important. LED signal modules offer the opportunity to provide a broader beam that provides a better opportunity to see the signal under fog conditions.

5.6 Flash Rate

The flash rate of incandescent signal lights is limited to about 60 flashes per minute by the rate at which the bulb turns on and off. For faster flash rates, the bulb may not get enough time to turn completely off. The current standard of 45-65 flashes per minute (Draft RTD10 Highway/Railway Grade Crossings, 2000) is not necessarily optimized for obtaining the best conspicuity of a signal, but is more based on what can be obtained with incandescent technology. With LED signals it is possible to increase the flash rate: LED signals can, in principle, turn on instantaneously, so any flash rate in (and beyond) the visible range can be achieved, as long as the drive circuitry does not impose limitations. The potential for using a faster flash rate is an advantage of switching to LED signals. The question is whether this advantage is beneficial, and whether a faster flash rate should be prescribed or recommended for LED signals.

Gerathewohl (1957) found that flashing lights were generally more conspicuous than steady ones of the same luminance contrast. For low luminance contrasts he found that signal conspicuity increased with increased flash frequency, up to 3 flashes per second. His most conspicuous signal was at 3 flashes/second with a luminance contrast of 1.0 or greater.

Conners (1975) found that there was little difference in the detection threshold as a function of stimulus modulation rate, though the 2-4 flashes/second range appeared to be most effective in terms of reaction time.

Hopkins and Holmstrom (1976) concluded that the most desirable flashing frequency for conspicuity was between 90 flashes per minute and three to four flashes per second.

The Federal Highway Administration conducted tests that showed that “flash rates exceeding 100 flashes per minute are significantly more effective than slower rates” They recommended flash rates of 110 flashes per minute for 8 inch railroad flashing pairs of light (FHWA-RD-77-167, 1977).

These four papers suggest that increasing the flash rate to two or three times a second would improve conspicuity. However, an experiment conducted by Tansley (1988) compared five different flash patterns for railway lights: 0.5 Hz out-of-phase (0.5 flashes/sec), 3 Hz (3 flashes/sec) in phase, 3 Hz out-of-phase, 5 Hz (5 flashes/sec) in-phase, and a “mixed modulation” signal in which segments of each of the first four signal rates were combined. The conclusion was that “all of the signals presented and evaluated here are about equal in providing rapid, simple reaction time responses by observers viewing the driving scene.”

As the rate of flashing is increased, there is some concern that the flash rate will cause undesirable physical effects on motorists. The issue is that a sub-class of people with epilepsy can have seizures induced by rapidly flashing lights. Photosensitive epilepsy is the term used to describe this condition. Less than 5% of people with epilepsy are photosensitive (Harding & Jeavons, 1994), so it is not a common condition. It mostly affects children, appearing between the ages of 8 and 20 years. The incidence is highest around ages 12 and 13, and girls are affected more often than boys. A quarter of patients lose their photosensitivity around 25 years of age.

Of the precipitation stimuli, television is the most common precipitant (60%), followed by flashing natural and artificial lighting. The sensitivity is flash rate dependent, as shown in

Figure 15. At three flashes per second only 3% of the photosensitive population are sensitive, rising to a maximum of 96% sensitivity at flash rates between 15 and 20 flashes per second (Harding, 1998). This data suggests that the maximum flash rate should be in the vicinity of 3 flashes per second to minimize the risk to those with photosensitive epilepsy.

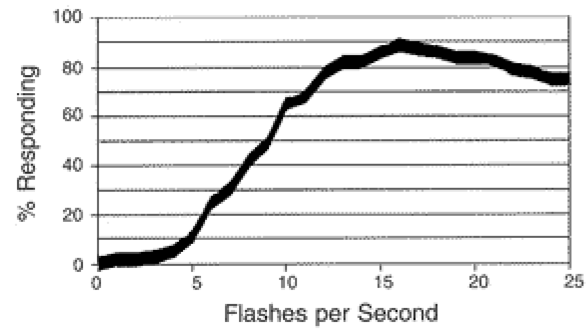


Figure 15 Photosensitive Population Response to Various Flash Rates (Harding and Jeavons, 1994)

While the papers above are not unanimous in their conclusions regarding the most effective flash rate, LED signals offer the ability to increase the flash rate as desired, and so are an improvement over incandescent signals, which are limited to the existing flash rates.

5.7 Rise and Fall Time

The rise and fall time refers to the time taken by a signal to reach full intensity from off, and vice versa. The rise and fall time for an incandescent bulb is on the order of 0.15 seconds or more, whereas an LED can turn on instantaneously. If we assume an instantaneous LED response, then the apparent luminous intensity of an LED signal can be compared with the apparent luminous intensity of an incandescent signal as shown in Figure 16.

If a signal reaches full intensity instantaneously, the conspicuity of the signal is improved significantly. For example, the effective luminous intensity (I_e) from a 0.5 second square wave produced by an LED signal is 0.91 of the maximum luminous intensity (I_{max}) according to Allard’s law, which estimates the ability of the eye to see a short flash. With an incandescent signal that turns on and off slowly, a sine wave is produced that has an effective intensity of 0.61 of its maximum intensity. For this example, the LED signal would appear 50% brighter than an incandescent signal with the same rated maximum intensity.

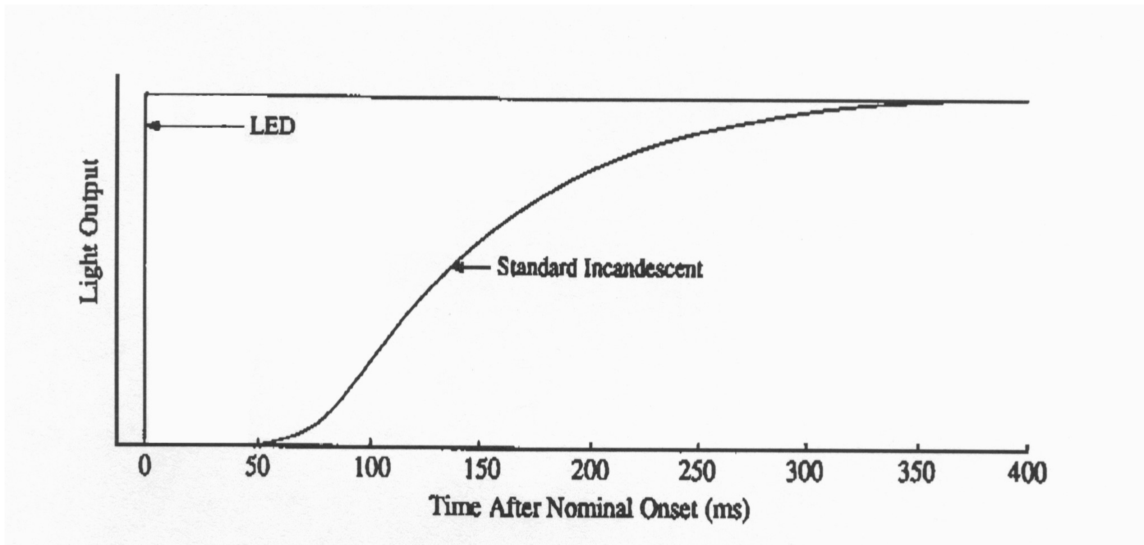


Figure 16 Light Output of Brake Lamps as a Function of Time After the Application of Voltage (Sivak et al., 1993)

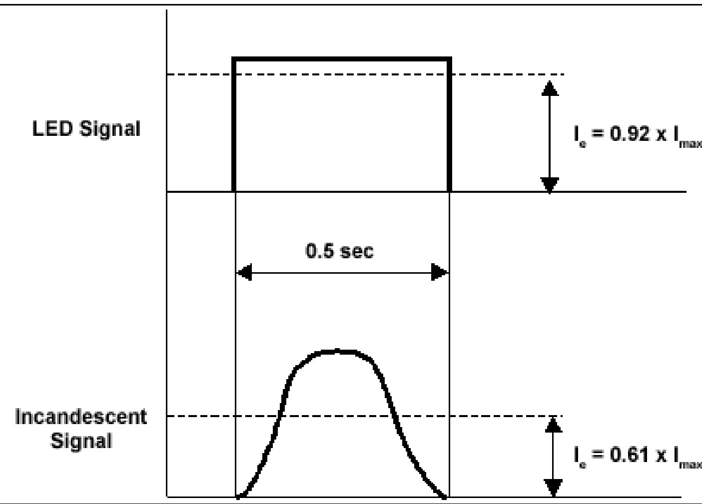


Figure 17 Comparison of Effective Light Outputs of Signals with Instantaneous and Slow Rise Times

5.8 Logarithmic Response of the Eye

In understanding the data regarding light output, it is important to realize that the human eye, like the human ear, is a logarithmic device.

For hearing we use decibels to describe sound output, a unit which is logarithmic. In light output, the units of measurement are not expressed in logarithmic units and the care must be taken in interpreting the data. A light producing 1000 cd will not appear to the human eye as ten times as bright as light producing 100 cd – the apparent difference will be about 7%.

The scientific references for the logarithmic response of the eye are numerous. Same examples are summarized below:

“Brightness, a subjective descriptor not possible to measure, is defined by CIE as the attribute of a visual sensation according to which an area appears to emit more or less light, therefore is a non-linear function of luminance. Human vision has non-linear response to brightness. This perceptual response to luminance is called by the CIE as LIGHTNESS, being roughly logarithmic for human eye” (Ferrer-Roca, 2001).

“Weber-Fechner Law ($L=cL_B$, $c=0.01 \ldots 0.02$) implies logarithmic relationship between physical luminance and subjectively perceived brightness” (Bernd, 2002).

“There is considerable experimental evidence indicating that subjective brightness, brightness as perceived by the human visual system, is a logarithmic function of the light intensity incident on the eye. This characteristic is illustrated in Figure 18, which is a plot of light intensity versus subjective brightness (Course notes on Human Vision, 1977).

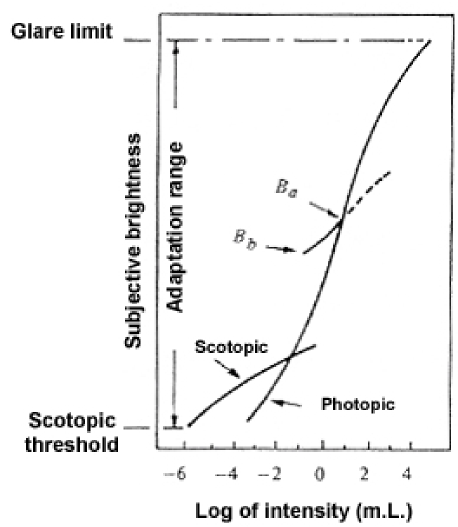


Figure 18 Light Intensity vs. Subjective Brightness

Comparing standards from various jurisdictions using a logarithmic scale versus a linear scale reduces the apparent difference between the standards considerably.

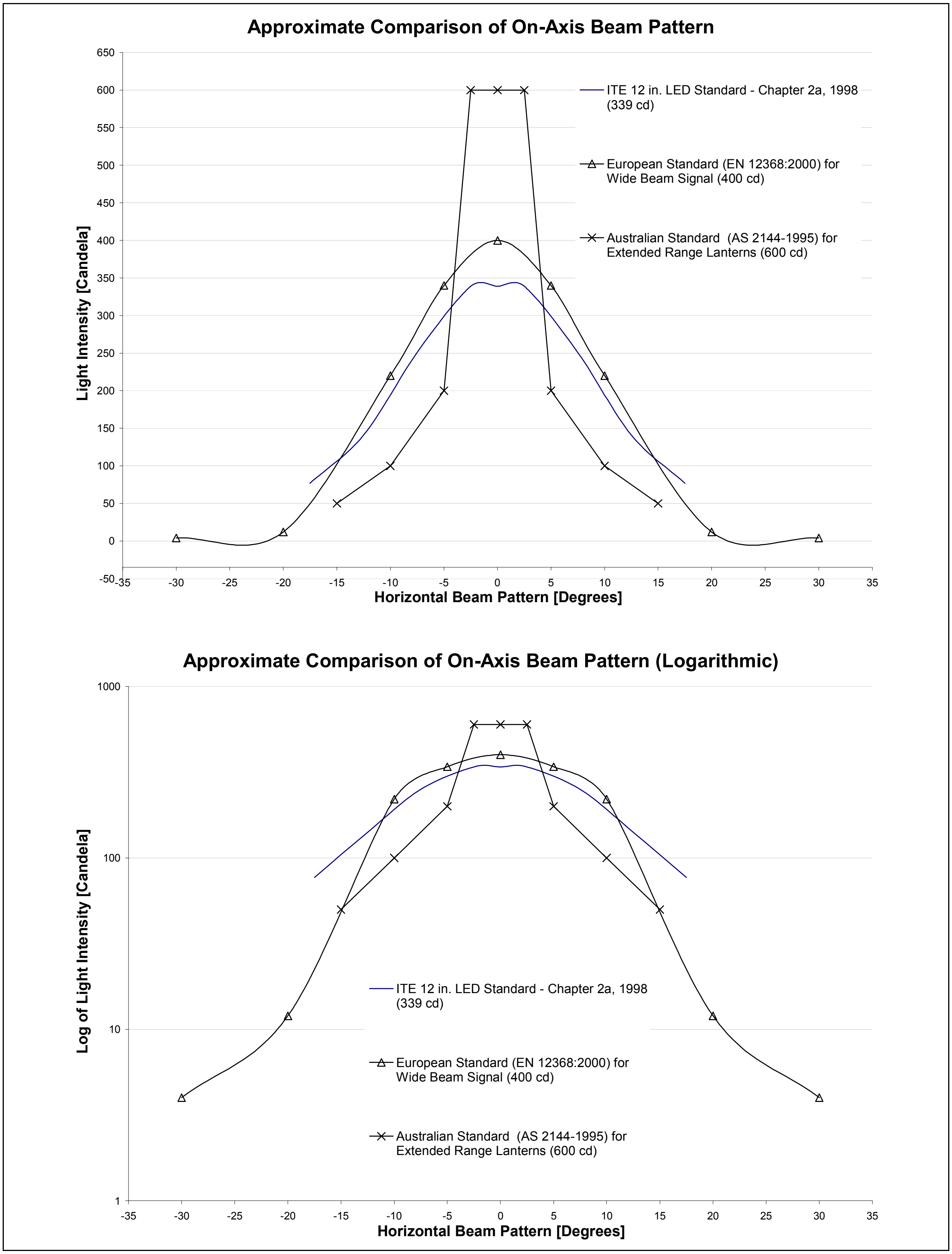


Figure 19 Comparison Between Linear and Logarithmic Interpretation of Data

5.9 Signal Size

Research performed by Cole and Brown (1968) indicated that signal size is not important because traffic signals are point sources rather than area sources when viewed from a distance, and therefore only intensity affects the visible range.

However, tests described in a report prepared for Federal Highway Administration (FHWA-RD-77-167, 1977) stressed the importance of illuminance (intensity times surface area) over intensity and showed that a 12 in. pair of flashing lights tested far better than a brighter pair of 8 in. flashing lights. They found that at 450 ft., without any intervening visibility restriction and with 10-12 ft. separating 8 in. and 12 in. heads, the two heads appeared “boldly” different in size.

In most highway jurisdictions 12 in. (300 mm) traffic lights are used for all challenging or high-speed locations, and 12 in. red signals are often used universally, with the green and yellow signals being smaller.

In the U.S., new LED signal lights being installed at highway-railway grade crossings are all 300 mm (12 in.). In Canada almost all of the installed base is 200 mm signals, and this size of signal has been accepted as satisfactory. Introducing LEDs into this size of signal will increase conspicuity due to the various factors, which have already been discussed. However, to further improve safety, converting these signals to 300 mm signals would be beneficial, since at closer ranges (less than about 200 m), the 300 mm signal will become much more conspicuous due to the fact that it has 2.25 times as much surface area.

5.10 Backgrounds

The issue of the size and colour of backgrounds has been discussed for decades. The practice of using black target boards around signal lights to increase their conspicuity has been investigated by Cole and Brown (1966) and Jainski and Schmidt-Clausen (1967). Both showed that as the screen size is increased, the signal intensity required is decreased. Cole and Brown pointed out that if the target board is a light colour, its luminance could rise to values approaching that of the sky. Jainski and Schmidt-Clausen showed that as the contrast between board and background is decreased, the signal intensity required rises sharply, possibly to or above the value required without a board.

Fisher and Cole (1974) recommend target boards of width at least three times the diameter of the signal and painted black matt colour.

More recently, yellow backgrounds have been used and have been found to be superior in some situations. Yellow backgrounds are very beneficial when the sun is in front of a signal, for signals on the side of the road against a backdrop of trees and buildings, on cantilever lights against a deep blue sky, and at night when black backgrounds are completely invisible. The other key advantage of yellow backgrounds and hoods is that they keep the temperature lower inside the signals, which is important for LEDs since LED signal performance is reduced with increasing temperature. The advantage of black backgrounds is that they improve signal visibility when the sun is high in the sky or when the sky is not very clear and blue (Coghlan, 1999).

The consensus of Transport Canada railway safety inspectors who attended an evaluation of LEDs with yellow backgrounds was that yellow backgrounds drew attention to the crossing and its signals even when the signals were not operating, and improved the conspicuity of the crossing and the warning system (Coghlan, 1999).

At the moment, in Canada, railway/highway grade crossings always use black backgrounds. However, highway traffic signals use both black and yellow backgrounds. The Manual of Uniform Traffic Control Devices (MUTCD) for Canada (section B3.2.3, 1998) recommends that "the backboard should be yellow, although flat black may be used where it is considered to be more effective".

5.11 Excessive Luminous Intensity

It is possible for the luminous intensity of a signal to be too bright at night, causing discomfort to drivers.

- Work done by the British Transport and Road Research Laboratory suggests a discomfort glare threshold for well-lit roads in order of 700 cd. The same study indicated a discomfort glare threshold in the order of 450 cd under poorly lit or unlit road conditions (Hulscher, 1975).
- Discomfort glare requirements based on the Rutley, Christie, and Fisher (1965) study are the following: 460 cd for high-speed open road opposing dipped headlights, 700 cd for normal shopping street, 350 cd for residential road, and 715 cd for city centre. All results were based on aiming, and assessing, the signals at a distance of 33 m.
- Section 4.1.2 of the ITE LED standard (Chapter 2a. 1998) states that "when operating within the temperature range specified in Section 3.1.1 during the warranty period, the maximum luminous intensity of the 8 in. or 12 in. signals shall not exceed 800 cd for the red,…".
- The European standard for traffic lights requires that traffic lights on high-speed roads have not more than 1000 cd (EN 12368:200).

Signal lights can be dimmed at night, but this introduces more complexity to the drive circuitry, increasing the chance that the circuitry will fail and reducing the chance of obtaining the 15 year life desired from the signal heads.

5.12 Conclusions re Human Factors

The above discussion of human factor issues related to the implementation of LED signals suggests that LED signals are either equal or superior to incandescent lights in all of the human factors considerations. There is no indication of any areas of difficulty or poor performance.

Red LEDs have now achieved very wide usage in traffic lighting, in brake lights for vehicles, and in related applications such as the rear light on bicycles. With an installed base of these lights now measured in the millions, practical experience shows us that there are no problems with the conspicuity of red LED signals, since these problems would have become very apparent by now. We conclude that the review of human factors and the accumulated practical experience suggest that LEDs offer an improvement in signal conspicuity and therefore in safety at highway-railway crossings.

6. DRIVER REQUIREMENTS

The underlying basis of the AAR and AREMA standards is the range required to give drivers sufficient warning of an approaching train. The obvious requirement is that drivers have time to brake to a halt after recognizing the signal. Therefore the signal needs to be sufficiently bright to alert the driver at the distance required to react.

The alignment requirements for the signal modules indicate the range required. The proposed Transport Canada Road/Railway Grade Crossings Technical Standards regarding alignment distances for various driver speeds are specified in Table 7. The maximum alignment distance, for an approach speed of 100 km/h, is 300 m or 1000 ft. The requirement that long-range roundels in signal modules have a range of 1500 ft. is presumably a safety factor so that the light will appear sufficiently bright at the alignment distance.

Table 7 – Alignment – Front Light Units (Part C – *Grade Crossing Warning System Technical Requirements*, RTD 10 Road Railway Grade Crossings, Draft, March 7, 2002)

Maximum Permissible Road Speed (km/h)	Recommended Distance Primary Set of Light Units (m)	Minimum Distance Primary Set of Light Units for Passenger Cars and Light Trucks (m)	Minimum Distance Primary Set of Light Units for Heavy Trucks (m)	Add for % Downgrade (m)		Substract for % Upgrade (m)	
				5%	10%	5%	10%
40	100	65	70	3	6	3	5
50	125	85	110	5	9	3	6
60	160	110	130	7	16	5	9
70	195	135	180	11	23	8	13
80	235	165	210	15	37	11	20
90	295	195	265	* For speeds exceeding 80 km/h distance shall be adjusted for gradient			
100	360	235	330				
110	390	275	360				

The beam patterns used in railway and highway traffic signal lighting have varied considerably in their beam patterns. Beam pattern shape should be determined by driver needs. Table 8 shows the change in vertical angle and horizontal angle as a driver approaches a signal light along a straight road.

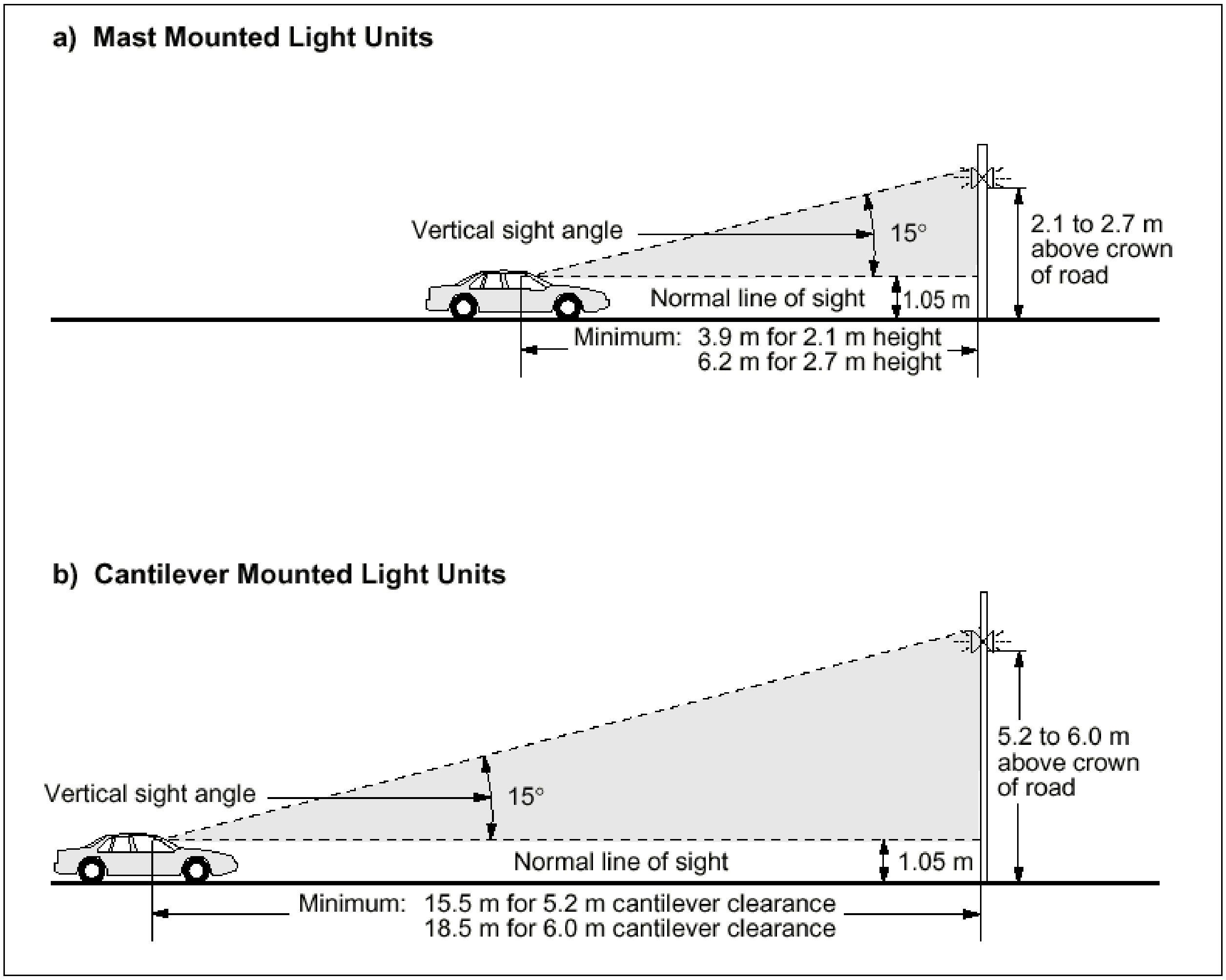


Figure 20 Vertical Cone of Vision (Part B – *Design Standards*, RTD 10 Road Railway Grade Crossings, Draft, March 7, 2002)

Table 8 – Vertical and Horizontal Angles Approaching a Mast Mounted Signal Light

Distance from signal (ft.)	Angle from vertical (assuming 10 ft. signal height, 4 ft. driver height)	Angle from horizontal (assuming 10 ft. offset from driver to signal)	Angle from horizontal (assuming 20 ft. offset from driver to signal)
1000	0.35	0.57	1.15
500	0.69	1.15	2.3
100	3.43	5.7	11.3
50	6.8	11.3	21.8
20	16.7	26.6	45
10	31.0	45	63

Table 9 – Vertical and Horizontal Angles Approaching a Cantilever Mounted Signal Light

Distance from signal (ft.)	**Angle from vertical (assuming 20 ft. signal height, 4 ft. driver height)**	**Angle from horizontal (assuming no offset from driver to signal)**
1000	0.92	0
500	1.83	0
100	9.1	0
50	17.7	0
20	38.7	0
10	58	0

The driver’s ability to see the signal head is influenced by three factors:

a) height of the driver’s eye;
b) windshield area; and,
c) vertical, horizontal and longitudinal position of the signal head.

Since the first two parameters are beyond the control of the signal designer, it is very important that the geometrics of each intersection be carefully examined to determine the optimum location for the signal head, as shown in Figure 20.

The horizontal position of the signal head is based on the driver’s cone of vision and the width of the intersecting streets. Studies show that drivers have excellent lateral vision up to 5° on either side of the centre line of the eye position (a cone of 10°), and adequate lateral vision up to 20° on either side. Therefore, it is desirable to have the primary signal head located within the 10° cone of vision, with the secondary head located within the 40° cone (as shown in Figure 21).

The horizontal angle varies up to twice as much as the vertical angle. If the road is not straight, but curves, the horizontal angle will increase further. These considerations suggest that it is more important to have a beam that is broad horizontally than a beam that is broad vertically. The AAR specifications in the past have beam patterns that are about 15 times as wide horizontally as they are vertically, which seems overly broad in the horizontal direction. The universal beam pattern suggested by AREMA in 1999 has a 1:1 ratio of horizontal to vertical (a circular beam pattern), which seems to be an over-correction from the very narrow beam used previously. Our specification follows the ITE lead in having about a 2.5:1 emphasis on horizontal beam pattern as opposed to vertical beam pattern.

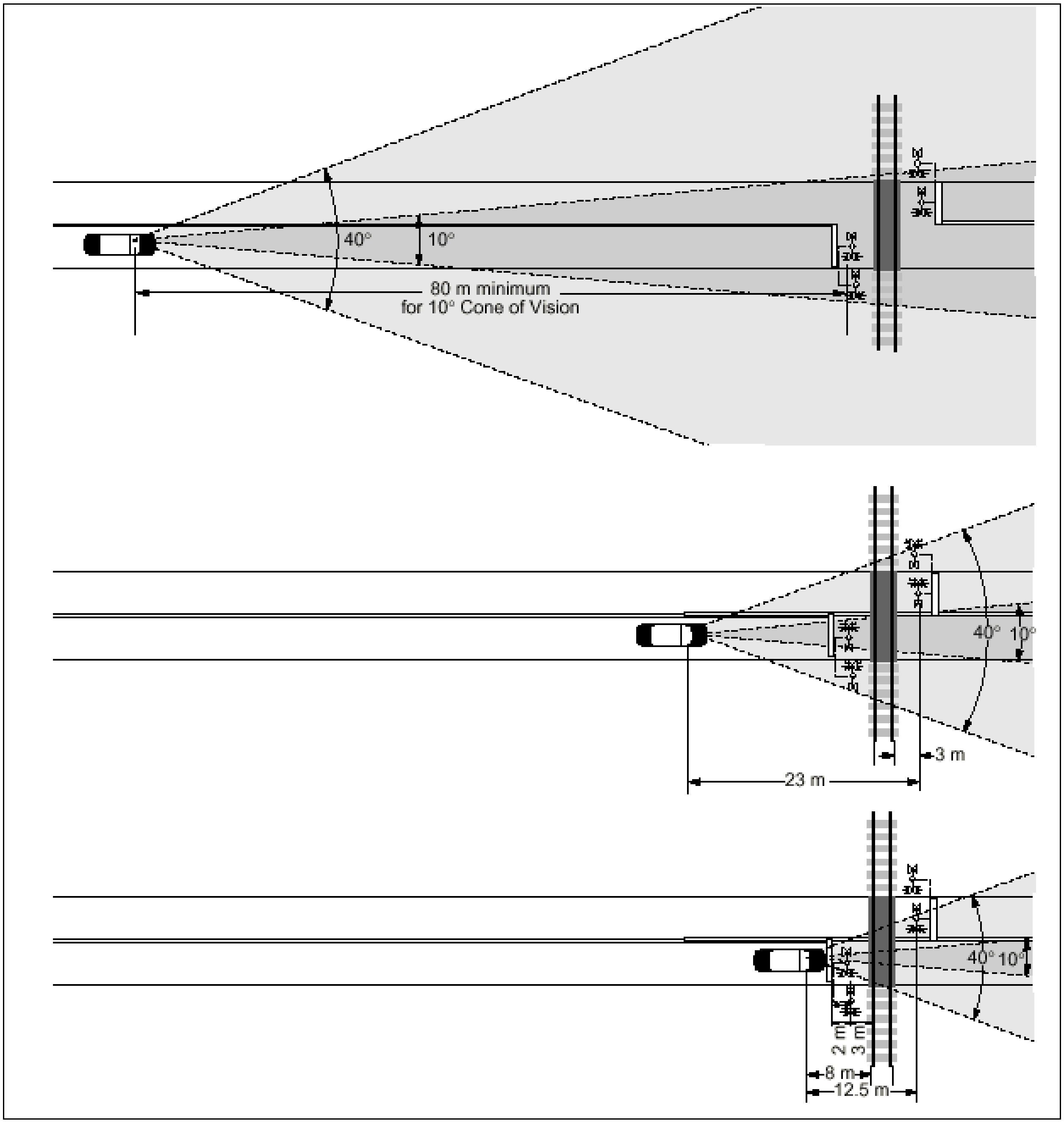


Figure 21 Horizontal Cone of Vision (Part B – *Design Standards*, RTD 10 Road Railway Grade Crossings, Draft, March 7, 2002)

6.1 Calculating Required Luminous Intensity from Driver Requirements

The current AREMA standard for the highway-railway crossing light requires a range of visibility of 1500 ft. (Manual Part 3.2.35, AREMA, 1999). This was also the range used by AAR up to 1968. In 1968, AAR converted this range requirement to a luminous intensity requirement of 1600 cd for narrow beam lights, and 1200 cd for wide beam lights. In 1996, AAR, in another standard for LED lights, converted the 1500 ft. range requirement to 160 cd with a much broader, circular beam pattern.

Calculating the required luminous intensity for a light to have a given range to drivers in daylight is difficult. The biggest factor affecting the viewing distance is the ambient daylight conditions or the illuminance. Other factors include size of signal, use of backplates, driver distraction, age of driver, colour vision deficiencies of driver, and sun location.

6.1.1 Highway Algorithm

The various recommendations in the scientific literature on traffic light luminous intensity and beam patterns for signal lights have, in large part, been derived analytically from research published by Cole and Brown in 1966 and 1968. Since these papers are so widely quoted, the key findings are summarized below:

Barry L. Cole and Brian Brown. 1966. *Optimum Intensity of Red Road-Traffic Signal Lights for Normal and Protanopic Observers*. Journal of the Optical Society of America, v 56, no.4.

Reaction times and missed signals were measured when subjects looked directly at the signal and when they performed a tracking task. The research led to the following conclusions:

Findings of this paper:

- 83-133 cd desirable for recognition of a red 8 inch signal at 100 m and background luminance of 2,136 cd/m^2;
- 160-260 cd desirable for recognition of a red 8 inch signal at 100 m and background luminance of 10,279 cd/m^2;

Barry L. Cole, Brian Brown. 1968. *Specification of Road Traffic Signal Light Intensity*. Human Factors, 10(3).

This research used subjects in a room observing a disc of light while performing tracking tasks resembling driving. The optimum intensity for a 100 m observation distance was found by applying the inverse square law to extrapolate from the experimental distance of 4 m to a distance of 100 m, and by simple proportion to extrapolate from the experimental background luminance of 600 ft-L (2056 cd/m^2) to 2919 ft-L (10^4 cd/m^2).

Optimum Luminance and Intensity for a Red Signal Light Computed from Experiment I

Signal Size min of arc	Criterion: base response time + 0.1sec	Criterion: "upper limit"
	Optimum Intensity [cd] for Observation from 100 m and Bgd Luminance 2919 ft-L (10^4 cd/m^2)	Optimum Intensity [cd] for Observation from 100 m and Bgd Luminance 2919 ft-L (10^4 cd/m^2)
4.1	158	582
5.5	68	154
8.2	57	193
11	65	162
16.5	77	165

- Optimum intensity does not depend on the angle subtended by the signal at the driver's eye for the practical range of values. For long range signalling it follows that a larger signal area gives no advantage over a smaller one of the same intensity and optimum intensity. A large diameter signal may be necessary simply to achieve intensity appropriate to the signalling distance but it is its capacity to provide a high intensity signal that would indicate its use; the larger area alone does not make the signal more effective.
- If two signals of different area have the same but less than optimum intensity, the smaller signal is more effective.
- Any value between 150 and 300 cd would be reasonable for optimum signal intensity when observing the light from 100 m against a sky luminance of 2919 ft-L (10^4 cd/m^2).
- Protonic drivers require a signal several times the intensity needed for normal vision drivers but a signal of optimum intensity for normal driver is likely to be seen by the "red-blind" driver with some certainty even though their response times may, on average, be some 200 ms longer.
- A design value as high as 8000 or 10000 ft-L for a sky luminance could be chosen since sky luminance near the horizon will exceed 2919 ft-L for several hours on clear days or days with light cloud over a horizontal arc of about 60°.
- A survey of traffic signals in Melbourne, Australia showed that an 8 inch red signal had an average intensity of 46 cd.
- The major result of this research was the development of a formula that defines optimum peak red signal intensity as a function of distance to signal and background luminance. The formula is as follows:

$$I_d = 2 \times d^2 \times L_b \times 10^{-6}$$

where

I_d = intensity at distance d [cd]
d = distance to signal [m]
L_b = sky luminance [cd/m^2]

Using the Cole and Brown formula to calculate the relationship between distance and the optimum peak red signal intensity, gives the following tables:

Assume Bright Sunlight Causing High Luminance (10,000 cd/m^2)

Signal Intensity (cd)	100	200	400	600	800	1000	1200	1400	1600
Range (m)	71	100	141	173	200	224	245	265	283
Range (ft.)	233	328	463	568	656	735	804	869	928

Assume Lower Luminance (3000 cd/m^2)

Signal Intensity (cd)	100	200	400	600	800	1000	1200	1400	1600
Range (m)	129	181	258	317	366	409	448	484	517
Range (ft.)	423	594	846	1040	1201	1342	1470	1588	1696

This algorithm requires an output of 4180 cd for bright days (10,000 lux) or 1253 cd for duller days (3000 lux) to have an optimum peak red signal intensity at 1500 ft.

This calculation shows at least a factor of three difference in the light output needed depending on the assumption that is made about the brightness of the day. Then, of course, there is the problem of defining what is meant by an ‘optimum peak’ red signal intensity. Cole and Brown were referring to the light required to produce an effective braking response. Whether this was what was intended by AAR in setting the viewing distance is unknown. More likely, this was the distance at which they felt that the signal could first be reasonably detected by an attentive observer.

6.1.2 Railway Algorithm

AAR (1968) uses a similar formula, but with a different constant, to calculate range from luminous intensity. Based on a formula by US&S and GRS, 1930 (Stated in a document by McKnight, 1999):

$$D = 161.25 \times \sqrt{BCP}$$

where

D = range of light in feet
BCP = beam intensity (in cd) measured after the lens.

(Formula apparently corrects for the fact that the original formula assumed that the light output would be measured without a lens, and that a red lens would have a transmissivity of 0.16.)

Signal Intensity (cd)	100	200	400	600	800	1000	1200	1400	1600
Range (ft.)	1612	2250	3225	3940	4580	5100	5600	5950	6450

This formula implies that only 100 cd is required to attain range of 1500 ft. The implication is that the requirement for being able to see the light is considerably different than the requirement for an ‘effective signal’ for braking purposes.

6.1.3 Marine Algorithm

Navigation lighting has perhaps the most rigorous control over beam patterns and intensities, since mariners, at least in the past, relied exclusively on navigation lights to find their way, without the benefit of roads or signs. The international body that sets the standards for navigation lights around the world is called the International Association of Lighthouse Authorities (IALA). The algorithm used by IALA is called Allard's law, and daytime ranges of lights are calculated based on assumptions about the minimum amount of light for the average human eye to detect a signal (the threshold of illuminance), and the clarity of the air (meteorological visibility). The specific wording around calculating daytime range is as follows:

The luminous range of a light is defined as the maximum distance at which a light can be seen, as determined by the luminous intensity of the light, the meteorological visibility, and the threshold of illuminance at the eye of an observer. The "nominal" range is the luminous range of a light when the meteorological visibility is 18.5 km (10 nautical miles), and the threshold of illuminance of 1000 microlux is used for daytime observation. Calculation of the "nominal" range is made using Allard's Law (International Association of Lighthouse Authorities, 1974).

$$E = I \cdot T^D / D^2$$

where

D = the distance between the observer and the light (metre)
T = the transmissivity of the atmosphere
E = threshold of illuminance [illuminance at the eye of the observer (lux)]
I = luminous intensity of the light (candela)

The relationship between transmissivity and meteorological visibility is given as:

$$T^V = 0.05$$

where

V = the meteorological visibility (metre)

Therefore, Allard's Law can be rearranged as:

$$I = E \cdot D^2 \cdot (0.05)^{-D/V}$$

Taking into consideration the assumed values for E and V, Allard's Law can be solved to give the following:

Signal Intensity (cd)	100	200	400	600	800	1000	1200	1400	1600
Range (m)	560	778	1074	1292	1471	1624	1760	1882	1994
Range (ft.)	1836	2551	3522	4238	4824	5327	5772	6173	6539

Plotting the daytime range as a function of luminous intensity gives the following curve:

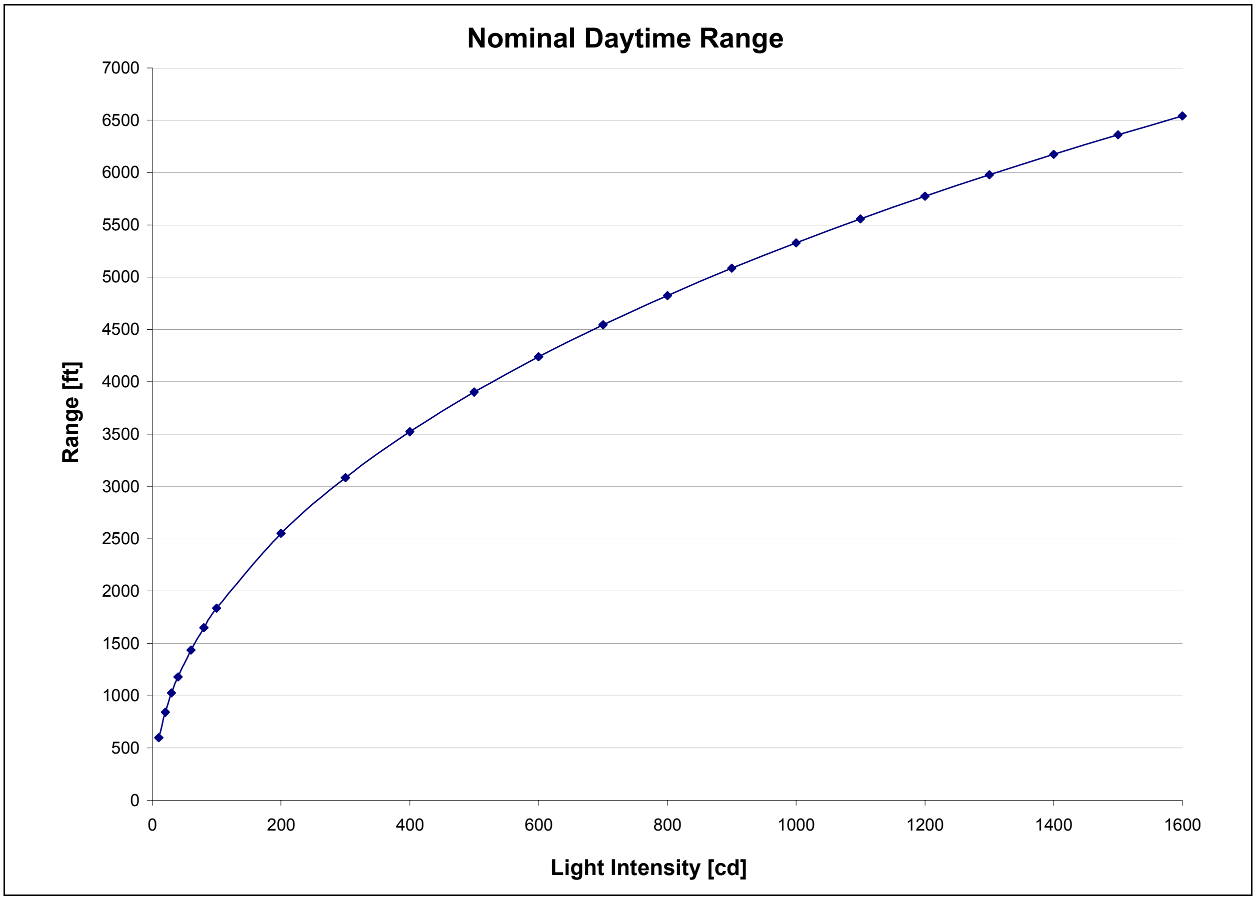


Figure 22 Marine Algorithm for Light Intensity versus Range in Daylight

Allard's Law is also used to calculate the nominal nighttime range. The only difference between the nighttime and daytime calculations is the threshold of illuminance (E): E is 1000 microlux for daytime (as seen above) and 0.2 microlux for nighttime (International Association of Lighthouse Authorities, 2001). The nighttime ranges are much higher, as shown in Figure 23.

Signal Intensity (cd)	100	200	400	600	800	1000	1200	1400	1600
Range (m)	10,043	12,062	14,270	15,641	16,648	17,448	18,113	18,683	19,182
Range (ft.)	32,940	39,564	46,804	51,304	54,607	57,229	59,410	61,279	64,376

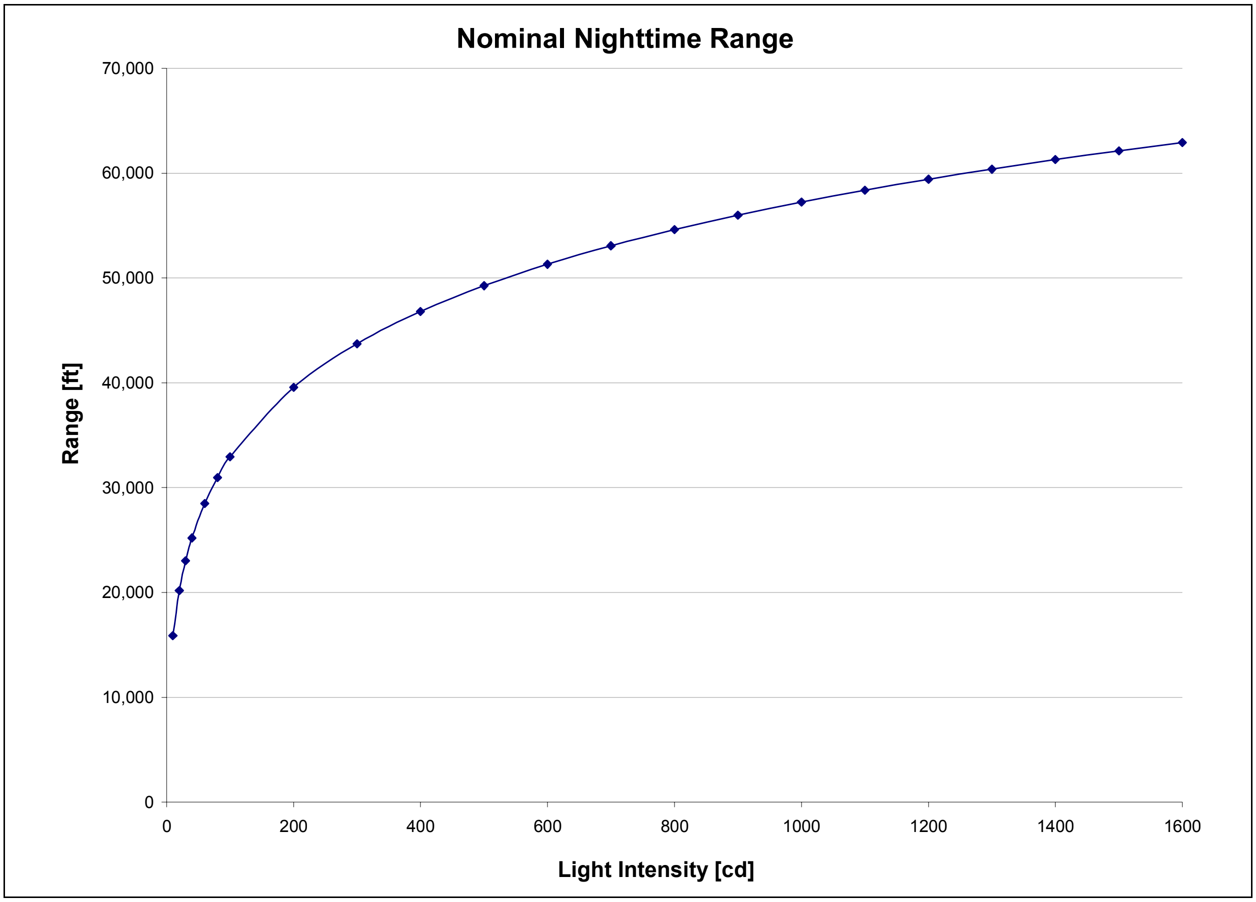


Figure 23 Marine Algorithm for Light Intensity versus Range at Night

The marine and railway algorithms suggest similar daylight candela requirements of about 100 cd for a range of 1500 ft. The Cole and Brown algorithm, which attempts to calculate the 'optimum' peak intensity for driver reaction, indicates a candela requirement of 4000 cd for 1500 ft. under the same conditions assumed by the other algorithms. These methods of calculating the luminous intensity from the drivers' requirements provide 'brackets' of the luminous intensity required, but do not provide a means of determining the 'correct' intensity.

6.1.4 Recommendations on Luminous Intensity from the Scientific Literature

This study is not alone in attempting to determine the correct luminous intensity for signal lights. The scientific literature, which deals almost exclusively with traffic light requirements, provides a number of specific recommendations for luminous intensity requirements. The following publications, listed in chronological order, provide scientific opinions on the luminance required for traffic lights:

- *W. Adrian, Lichttechnik 15, 115 (1963):* 200 cd intensity is recommended in order to see 8 in. signal with a sky luminance of 3000 cd/m^2 (quoted in Cole & Brown, 1966).
- *H. Boisson and R. Pages. 1964. Compt.Rend., 15th Session Vienna (CIE Publication No. 11D):* 200 cd is sufficient with a background luminance of 10^4 cd/m^2 at 100 m distance (quoted in Cole & Brown, 1966).

- *Unpublished report of the Road Research Laboratory, England*: for a red 8 in. signal viewed from 400 yd. (366 m) an intensity of about 600 cd is necessary under bright sunny conditions. At a viewing distance of 200 yd. (183 m), an intensity of 400-500 cd was required (quoted in Cole & Brown, 1966).
- *Cole and Brown (1966)*: protanopic observers require a signal of about 4 times the luminance required for normal drivers; this entails an intensity of at least 600 cd for an 8 in. signal.
- *Hulscher (1975)*: a red signal requires a peak intensity of 895 cd for a distance of 240 m without the backplate. In analytic computations based on Cole's work, Hulscher also has shown that a 12 in. signal requires 1/3 less intensity with a backplate (100 km/h speed, 10,000 cd/m^2 sky luminance, distance of 240 m) which drops the required luminous intensity from 895 cd to 600 cd.
- *Fisher and Cole (1974)*: for a high-speed road, only an *11% reduction in intensity* is possible from 895 cd to 800 cd because of the smaller effect of the backplate at these longer distances.
- *Corbin et al. (1995)*: the required intensity for a red ball LED signal seems to be in the range of 300-500 cd with a narrow distribution (7° viewing angle). The intensity required for red ball LED signals can be reduced by about 26% to 52% if the distribution is doubled.
- *Janoff (1990)*: combining the use of backplate (as a conservative approach) with a depreciation factor of 33% yields a red peak intensity for new signals of 1060 cd for 12 in. signal (895 cd by 0.89 by 1.33), where 0.89 represents 11% reduction due to a backplate
- *Pezoldt et al. (1997)*: light output shall be a minimum of 860 cd measured along the principal optical axis of the LED array at a distance of 50 ft. (12.7 m).
- *Sullivan et al. (1997)*: the calculated desirable peak intensity for viewing at a distance of 240 m is 541 cd.
- *Staplin et al. (1997)*, in a large study of the requirements of older drivers, argued for higher standards than are currently in use by ITE. They do not present original work, but review the literature to ascertain the information that is relevant to older drivers. The two driver characteristics that they considered with regard to adjustments in peak intensity requirements were colour anomalies and driver age. They quote Cole and Brown (1968) who determined that the optimum red signal intensity is 200 cd for a sky luminance of 10,000 cd/m^2; adequate signal intensity would be 100 cd. (A traffic signal of "optimum" intensity resulted in subjects reacting within 0.1 seconds of their minimum reaction time. A signal of "adequate" intensity resulted in a slower reaction time, but was still judged "not likely to be missed".) About 2% of males are afflicted with a decrease in sensitivity to red light. The optimum intensity for the red signal for these drivers with colour deficiencies, according to Cole and Brown (1966), is larger than 600 cd (more than three times the optimum intensity for individuals with normative colour vision performance), and according to Fisher (1969) is about 720 cd. Fisher and Cole (1974), using data from Blackwell (1970) point out that drivers need 1.5 times the intensity at age 50 and 3 times the intensity at age 70. They note that while increased intensity will ensure that older observers see the signal, the reaction time of older drivers will be longer than for younger drivers.
- *NCHRP (2001) 5-15 Project*: the most recent study on the intensity requirements for traffic signals. This report concludes: "Consequently, we suggest that for less demanding (more routine) conditions, a performance level of about one-half our laboratory findings (i.e., consistent with Cole and Brown (1968) and Fisher (1971)) would be appropriate [200 cd]. For those situations in the highest speed categories, intensities should follow Hulscher's recommendations [600 cd after backplate]".
- *Staplin et al. (1997)* concludes that "Most of this literature is analytical; very few empirical studies have been reported. The few empirical studies that have been done are either laboratory studies or have used field techniques with methodologies that limit

generalization." "To place this discussion in context, it should also be noted that traffic signal recommendations for different sizes, colours, and in-service requirements have, in large part, been derived analytically from one research study conducted by Cole and Brown (1966)."

6.2 Conclusions re Driver Requirements

The algorithms for calculating the luminous intensity necessary to provide 1500 ft. of range in daylight conditions require between 100 cd at a minimum to 4000 cd as a 'peak optimum'. The scientific literature narrows the range of recommended luminous intensities. Including only the recommendations for high-speed roads, and leaving out allowances for degradation where they are mentioned, the scientific literature narrows the recommended intensities to between 300 and 800 cd. Above 800 cd, the scientific literature indicates that the signal lights may be excessively bright at night (see section 5.11).

In order to further narrow down the luminous intensity required of LED signal lights, we conducted a series of field and laboratory experiments designed to produce information that would help decide on a required luminous intensity in the range of 300 to 800 cd.

7. FIELD AND LABORATORY TESTING

In order to obtain information on the actual performance of LED signal modules, we obtained samples and prototypes from various manufacturers with varying light outputs. The luminous intensities and beam patterns of these LED signal modules were characterized in the laboratory, and four pairs of signal modules covering the range of 300 to 800 cd were chosen for a series of field and laboratory experiments. Unless otherwise specified, all of the luminous intensities were measured at 10.5 V, which is the upper end of the voltage range that a railway crossing signal will see during its normal operation. In Canada, signals are set to operate in a nominal range of 9 to 10 V. In the U.S., the voltage can be as low as 8.5 V. The impact of voltage on luminous intensity for incandescent bulbs is shown in Figure 46 in section 12.1.

Table 10 – Photometric Characteristics of Sample LED Signal Modules

TEST PERFORMED		**Light #1**	**Light #2**	**Light #3**	**Light #4**
Beam Description		ITE Type	ITE Type	Wider horizontally and narrower vertically than ITE	Round Beam
Luminous Intensity	*On Axis*	636 cd	635 cd	956 cd	374 cd
	5° Down	797 cd	675 cd	190 cd	162 cd
	10° Down	293 cd	362 cd	41 cd	31 cd
	15° Down	133 cd	90 cd	30 cd	12 cd

LED SIGNAL #1

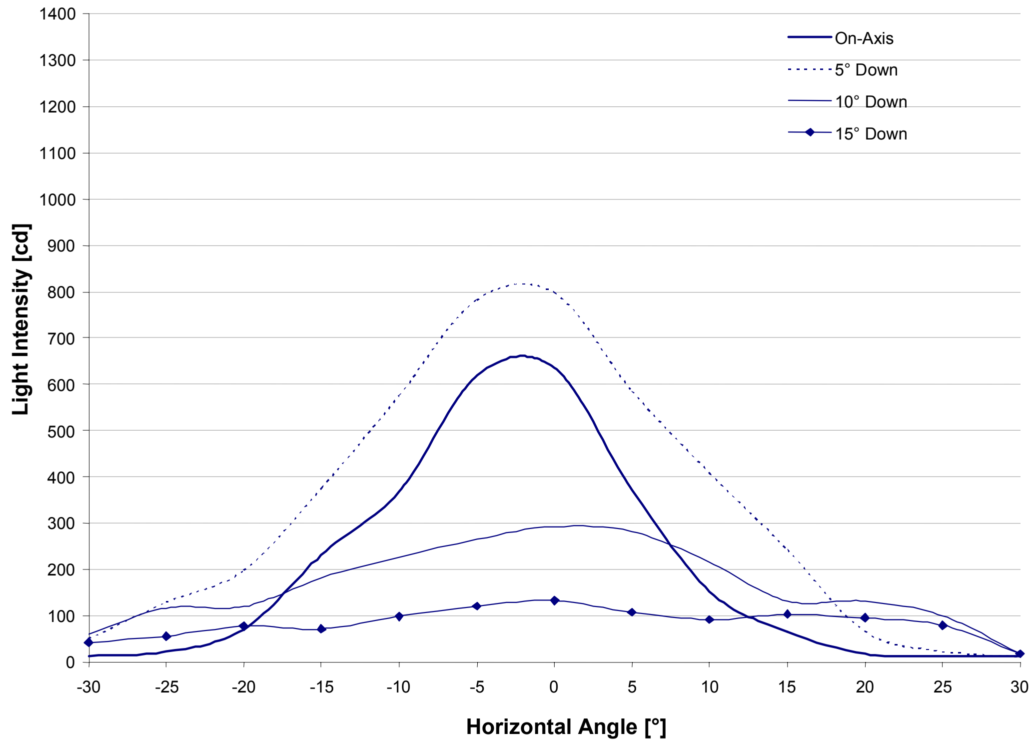


Figure 24 Beam Pattern for LED Signal #1

Table 11 – Measured Luminous Intensity for LED Signal #1

	30° L	*25° L*	*20° L*	*15° L*	*10° L*	*5° L*	*0°*	*5° R*	*10° R*	*15° R*	*20° R*	*25° R*	*30° R*
0°	14	22	72	232	368	619	636	371	153	65	18	13	12
5° D	50	129	198	376	575	782	797	585	408	243	66	23	12
10° D	61	117	120	182	227	265	293	282	216	132	132	100	17
15° D	42	56	78	72	99	121	133	108	92	103	95	80	18

LED SIGNAL #2

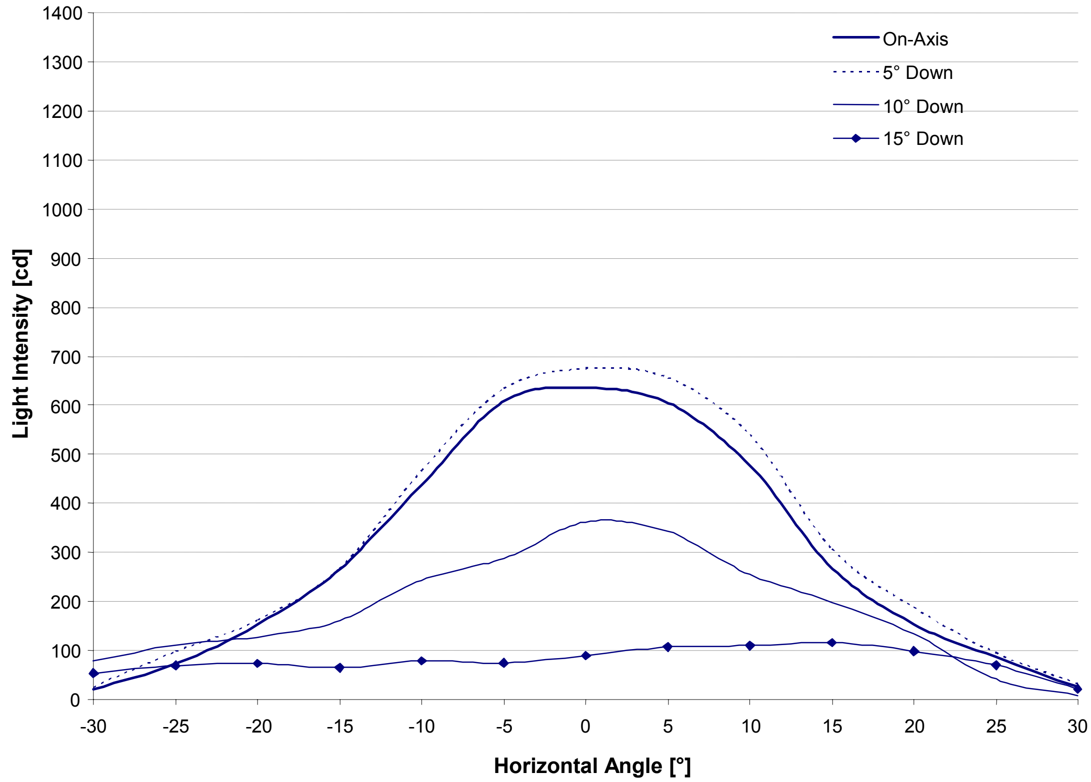


Figure 25 Beam Pattern for LED Signal #2

Table 12 – Measured Luminous Intensity for LED Signal #2

	30° L	*25° L*	*20° L*	*15° L*	*10° L*	*5° L*	*0°*	*5° R*	*10° R*	*15° R*	*20° R*	*25° R*	*30° R*
0°	21	73	153	266	437	609	635	605	478	267	154	86	26
5° D	26	98	161	267	467	634	675	656	540	307	188	95	32
10° D	79	111	128	161	244	288	362	343	255	199	134	41	9
15° D	54	69	74	65	79	75	90	107	110	116	99	70	22

LED SIGNAL #3

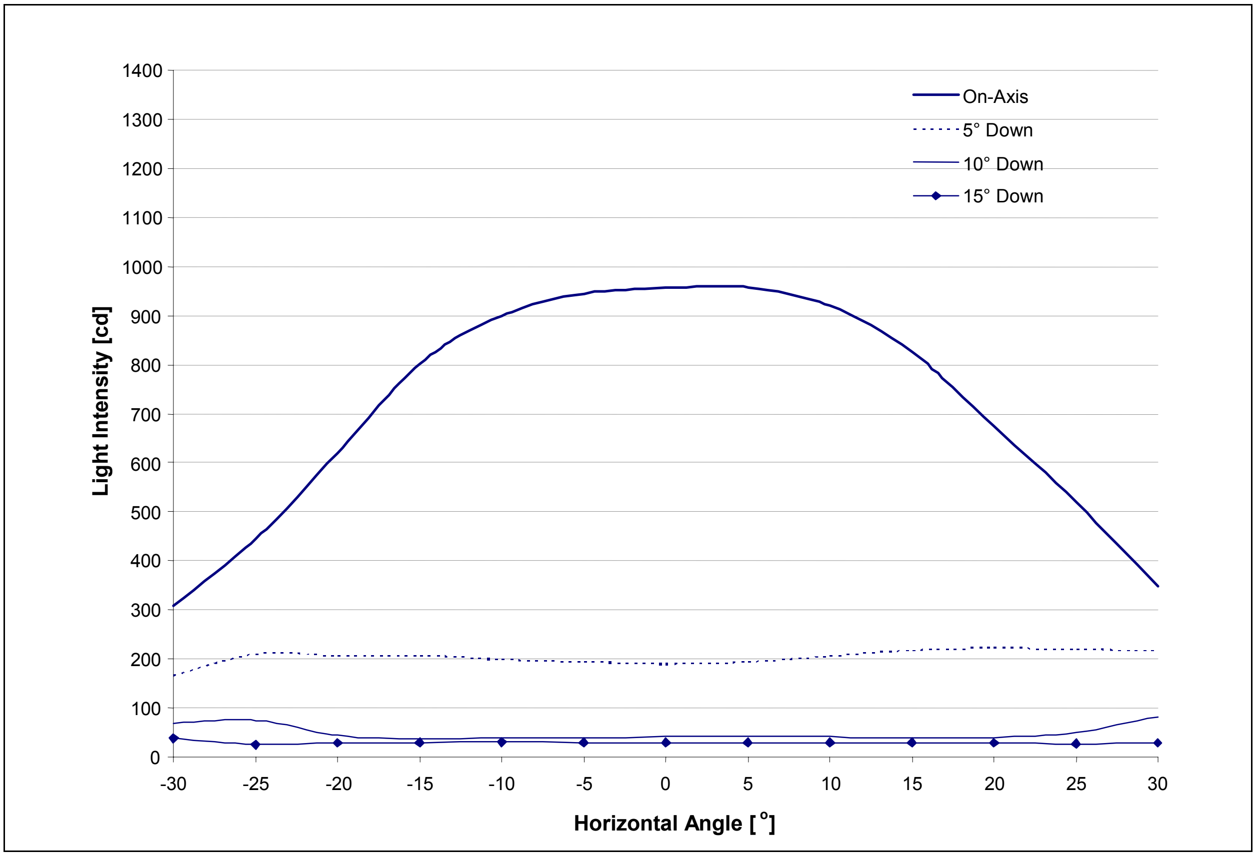


Figure 26 Beam Pattern for LED Signal #3

Table 13 – Measured Luminous Intensity for LED Signal #3

	30° L	*25° L*	*20° L*	*15° L*	*10° L*	*5° L*	*0°*	*5° R*	*10° R*	*15° R*	*20° R*	*25° R*	*30° R*
0°	308	445	620	802	900	945	956	958	920	826	674	520	349
5° D	166	210	207	208	199	194	190	194	206	218	222	220	217
10° D	69	75	44	38	39	40	41	41	41	39	40	50	83
15° D	39	26	29	30	31	30	30	30	30	30	29	27	29

LED SIGNAL #4

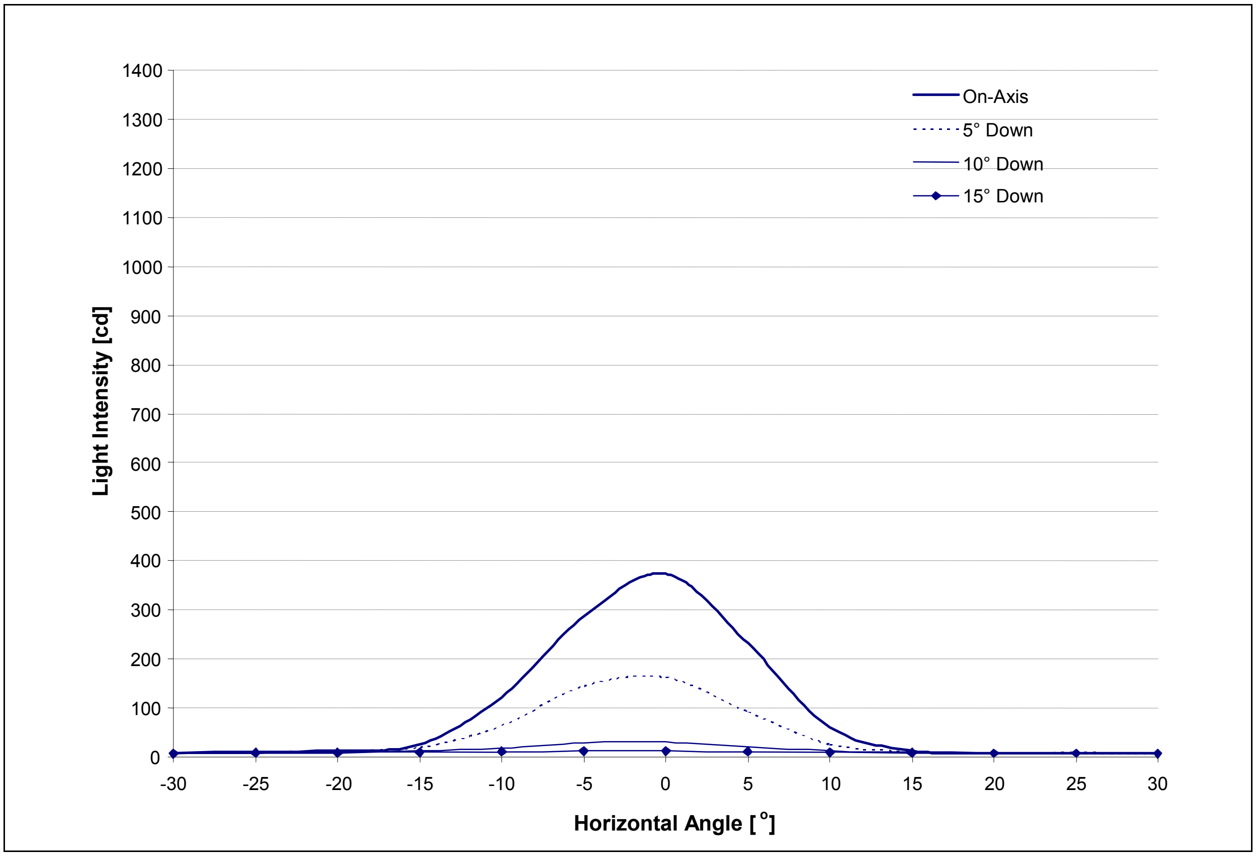


Figure 27 Beam Pattern for LED Signal #4

Table 14 – Measured Luminous Intensity for LED Signal #4

	30° L	***25° L***	***20° L***	***15° L***	***10° L***	***5° L***	***0°***	***5° R***	***10° R***	***15° R***	***20° R***	***25° R***	***30° R***
0°	9	11	14	26	122	287	374	231	61	13	9	8	7
5° D	8	10	12	20	64	145	162	92	26	11	9	8	7
10° D	8	9	10	13	18	30	31	22	13	10	9	8	7
15° D	7	9	9	10	11	12	12	11	10	9	8	8	7

OLDER 8 INCH INCANDESCENT MODULE TAKEN OUT OF SERVICE

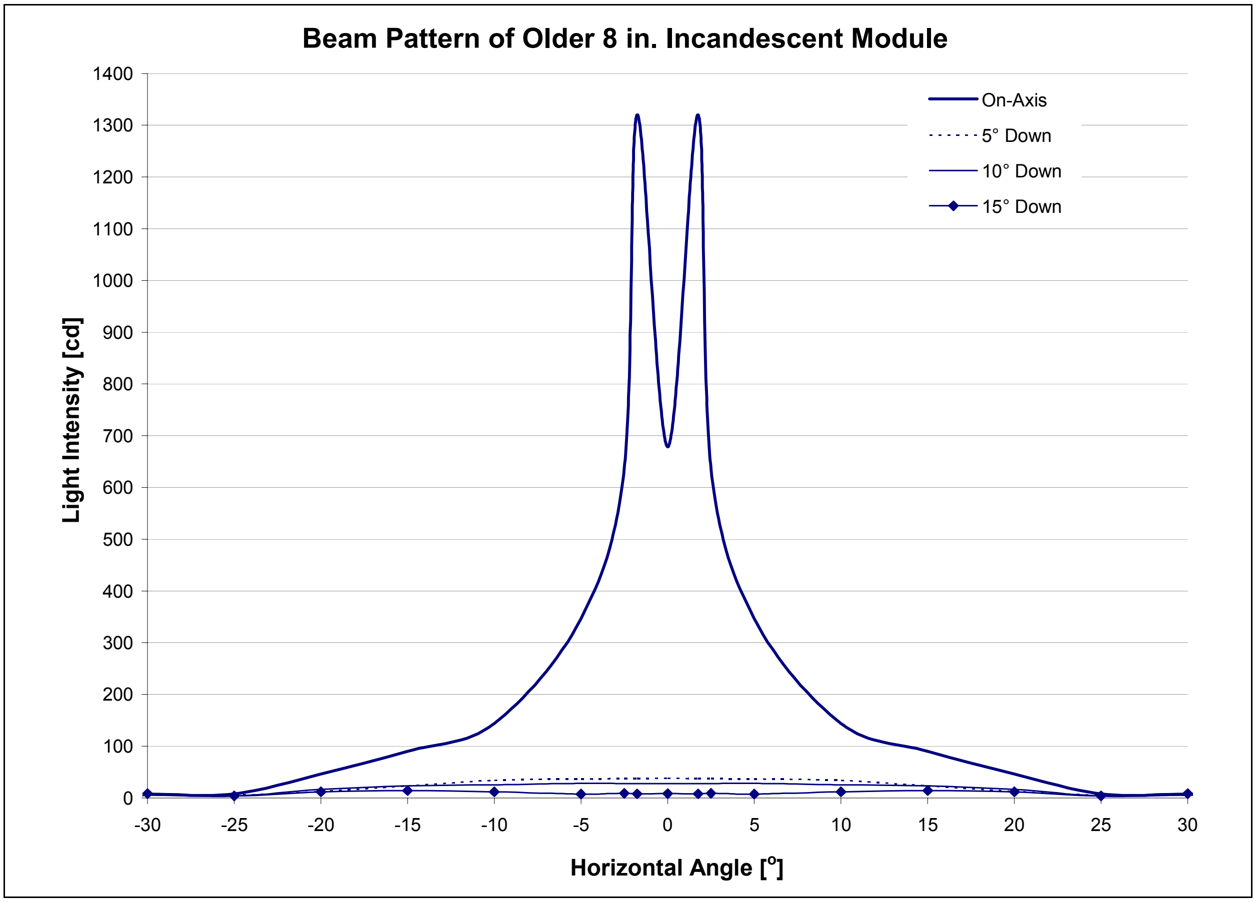


Figure 28 Beam Pattern for an Older 8 in. Incandescent Signal Taken Out of Service (30-15° roundel, 18 W bulb, tested at 10.5 V)

Table 15 – Measured Luminous Intensity for Older 8 in. Incandescent Signal

	35° L	*30° L*	*25° L*	*20° L*	*15° L*	*10° L*	*5° L*	*2.5° L*	*1.75° L*	*0°*	*1.75° R*	*2.5° R*	*5° R*	*10° R*	*15° R*	*20° R*	*25° R*	*30° R*	*35° R*
0°	9	7	8	46	90	144	347	638	1320	679	1320	638	347	144	90	46	8	7	9
5° D	0	5	5	12	23	34	37	37	37	37	37	37	37	34	23	12	5	5	0
10° D	0	6	3	16	23	25	28	28	28	28	28	28	28	25	23	16	3	6	0
15° D	0	8	4	12	14	12	8	9	8	8	8	9	8	12	14	12	4	8	0

7.1 Field Test #1

The first experiment was designed and completed to answer the following questions:

1) Are the LED signal modules with broad beam patterns and luminous intensities of 300 cd to 800 cd brighter and more effective than standard incandescent lights?
2) Are the LED modules visible at the AREMA required distance of 1500 ft. during bright daylight conditions?
3) Is the beam pattern sufficiently broad to accomplish the goal of covering off the beam patterns from the 30-15°, 20-32° and the 70° roundels used for incandescent lights?
4) Are the LED modules too bright at night?

The attendees of the Steering Committee Meeting on September 24-25, 2001 evaluated the four pairs of LED railway lights, and one pair of older style 8 in. incandescent lights.

7.1.1 Methodology

The signal modules were tested at Heal's Firing Range belonging to the Department of National Defence. This facility allowed a focus group to evaluate the performance of the signal lights rigorously. Heal's Firing Range consists of 24 firing lanes with firing berms spaced at 100 yd. increments, to the 600 yd. berm. At the 600 yd. berm the increments to the next berm increase to 200 yd. The range is 1200 yd. long and 100 yd. wide (Figure 29). The start of each lane is marked with a numbered target that sits at the top of a 20 ft. high berm from the observer's point of view. The width of each target is 1.55 m and the distance in between each target is 2.75 m (Figure 30). The signal lights were mounted in pairs, one pair in front of each target.

Figure 29 Looking Down Heal's Firing Range Toward the Target Berm

Figure 30 Signal Lights on the Target Berm of the Firing Range

Pairs of lights were mounted on individual sawhorses with 31 in. separating the lights in each pair (same as normal spacing when in service). Figure 31 and Figure 32 show the test arrangements.

Figure 31 Side View of Signal Light Test Arrangement

Figure 32 Rear View of Signal Light Test Arrangement

Pairs of lights were spaced equally and arranged in front of sequential lane targets as follows:

- Lane 1 – LED #1
- Lane 2 – LED #2
- Lane 3 – 8 in. Incandescent
- Lane 4 – LED #3
- Lane 5 – LED #4

The five pairs of lights were wired to one Union Switch & Signal Flasher. Two 12 V batteries were used to power the flasher and five pairs of lights. A 12 V battery charger charged both batteries to ensure the proper voltage was sustained throughout the experiment. A generator was used to power the battery charger. One 12 V battery was connected through a dropping resistor to supply 10.5V to the flasher and three pairs of lights. The three pairs of lights powered at 10.5 V were LED #3, LED #4 and 8 in. incandescent. The other two pairs, LED #1 and LED #2, were powered at 12 V from the second 12 V battery. The same flash rate was applied to the five pairs of lights.

The incandescent lights used in this experiment were taken out of service from the E&N railway and were in older GRS steel housings. GE 18 W bulbs were used. The lenses and mirrors were cleaned prior to the test. All of the signals were aligned by using a level to ensure they were vertical, and by pointing them straight down the range.

7.1.2 Evaluation Protocol

The field test began at 2 pm on 24 September 2001. It was a clear sunny day and daylight intensity was measured to be 50,000-60,000 lux. A group of eleven evaluators started at the 1000 yd. berm and then proceeded to the 800 yd. berm, evaluating lights from directly on-axis and recording results. At 600 yd. the group split into two, and one group went to each of the sites in Table 16. At the 50 ft. berm both groups made observations on all lights in firing lanes 3, 7 and 10. All evaluations were completed by 4 pm.

Table 16 – Summary of Evaluation Points for Field Test #1

Lane	**3**	**7**	**12**	**24**	
	Horizontal Angle (°)				Vertical Angle (°)
50 ft. Berm, below	0	15			18
50 ft. Berm	0	15	30		8
100 yd. Berm	0		19	37	3.5
200 yd. Berm	0			24	1.6
300 yd. Berm	0			15	1.1
400 yd. Berm	0			12	1.0
500 yd. Berm	0			8	0.8
600 yd. Berm	0			6	0.7

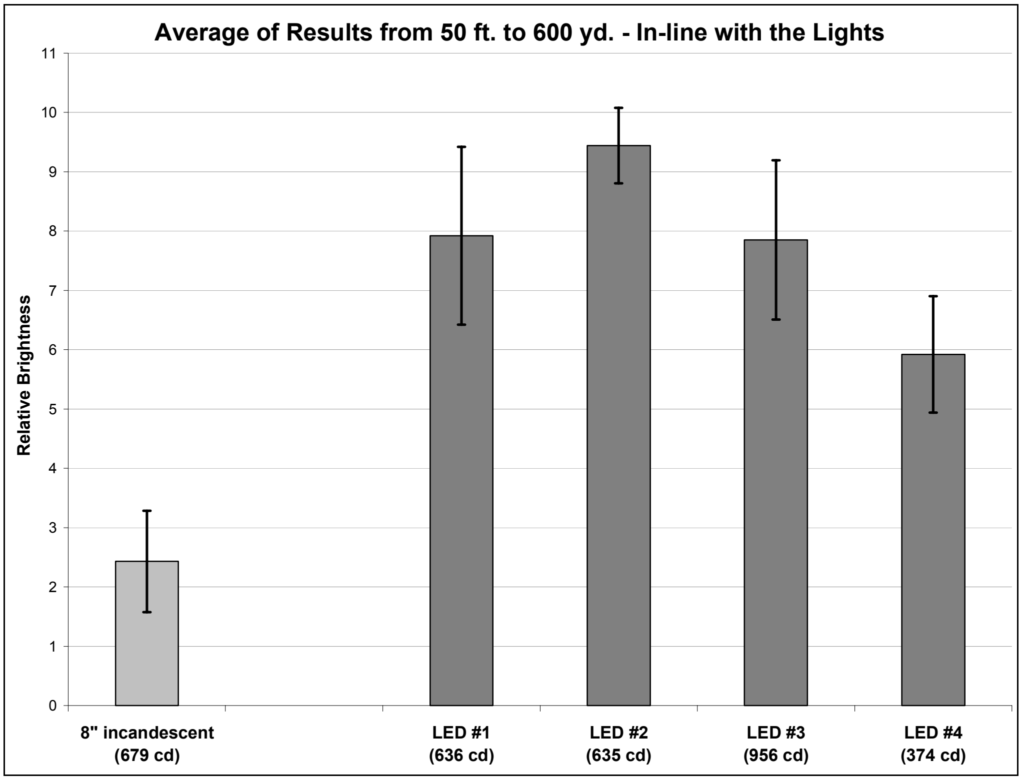

Figure 33 Focus Group Observing Lights

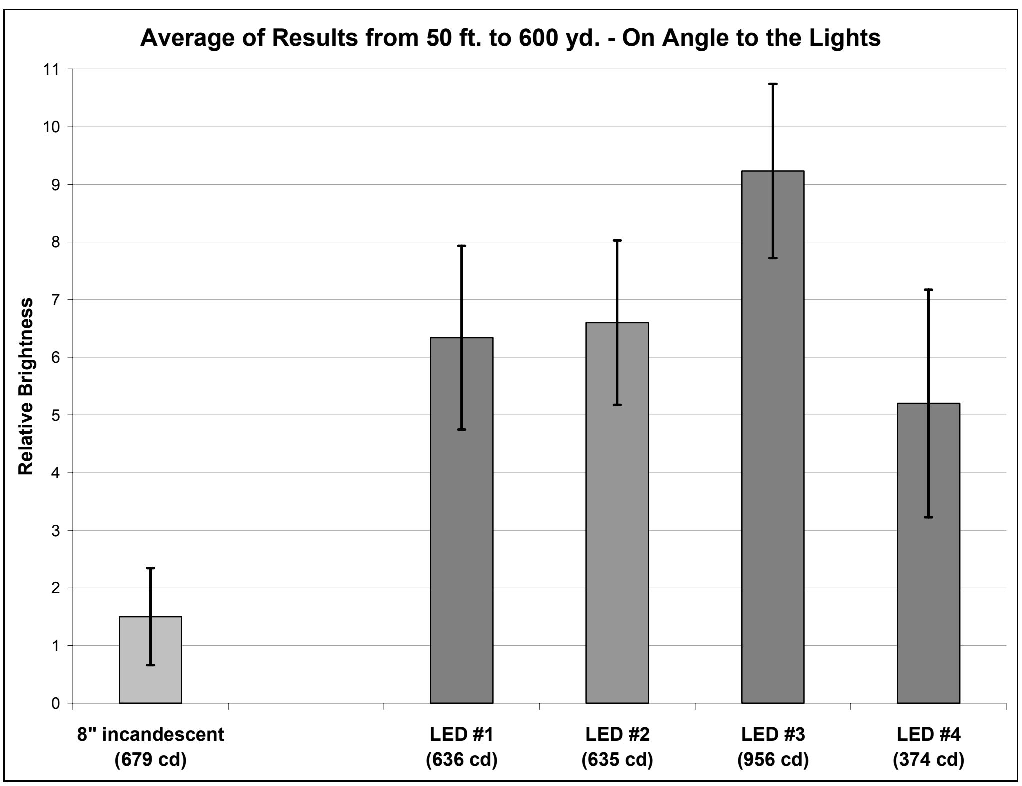
Six evaluators returned to the firing range at 9:30 pm to observe the signals at night. Evaluations were made from the 1000 yd. berm to the 50 ft. berm.

For both daytime and nighttime tests the signals were evaluated on a scale from 0 to 10. A rating of 10 indicated that the signal was the most conspicuous at that position. The rest of the signals were ranked compared to the most conspicuous. 0 indicated that the light was not visible at that position and 5 indicated that it was rated half as bright as the most conspicuous signal.

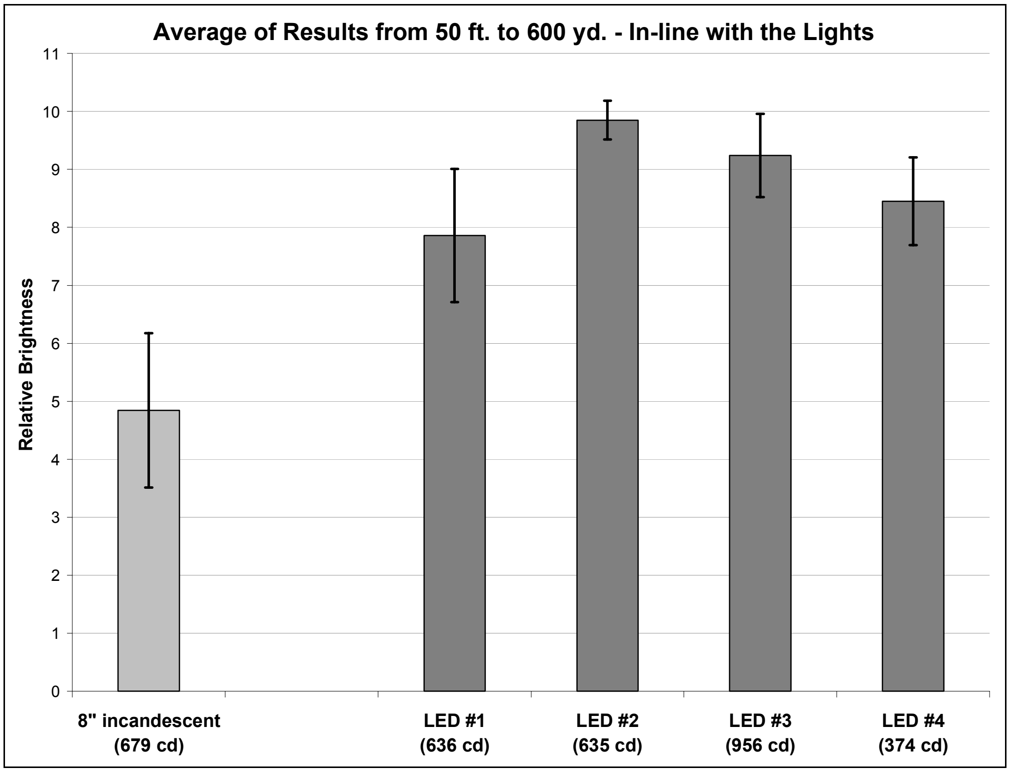
7.1.3 Results of Field Test #1

DAYTIME

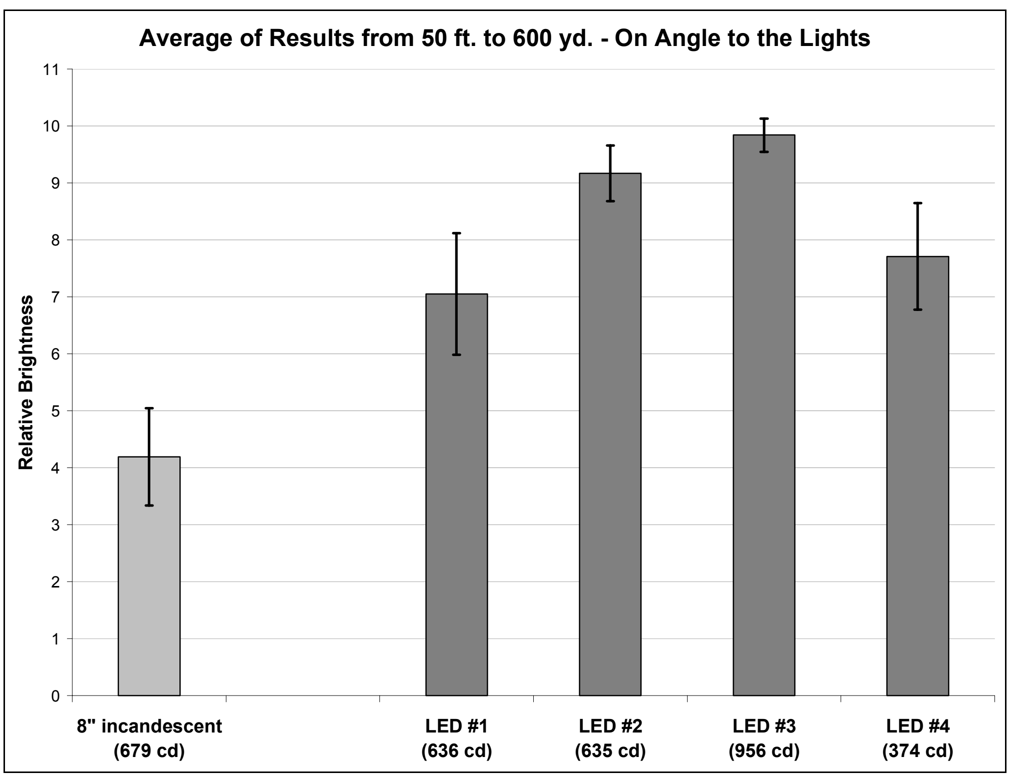




NIGHTTIME



Average of Results from 50 ft. to 600 yd. - In-line with the Lights
Relative Brightness
0
1
2
3
4
5
6
7
8
9
10
11
8" incandescent (679 cd)
LED #1 (636 cd)
LED #2 (635 cd)
LED #3 (956 cd)
LED #4 (374 cd)



Average of Results from 50 ft. to 600 yd. - On Angle to the Lights
Relative Brightness
0
1
2
3
4
5
6
7
8
9
10
11
8" incandescent (679 cd)
LED #1 (636 cd)
LED #2 (635 cd)
LED #3 (956 cd)
LED #4 (374 cd)

7.1.4 Conclusion re Field Test #1

All of the LED signals clearly outperformed the old style 8 in. incandescent signals.

The improved performance of the LED signals over the incandescent signals was more apparent during daylight than at night.

All signals were clearly visible at the AREMA required distance of 1500 ft.

Of the LED's tested LED #1, LED #2 and LED #3 were found to have sufficiently broad beam to be suitable for all lens requirements.

LED #4 was a round beam (no secondary lens) and it was inadequate at larger horizontal observation angles.

LED signals #1 and #2 were very bright at night, but not to the point that they were judged inappropriate.

The steering committee felt that the experiment should be repeated with new incandescent signals of both 8 in. and 12 in. sizes that were very carefully aligned, so as to be sure that the incandescent results were the best possible, and that the focus group be made up of a broader age spectrum.

7.2 Field Test #2

The purpose of the second experiment was to repeat the test procedures from the first experiment, but with new incandescent signals and improved alignment procedures, and see whether the LED signals still outperformed the incandescent signals.

7.2.1 Methodology

The incandescent lights were upgraded to one new 8 in. light and one new 12 in. light. The beam patterns for the new incandescent signals were much better than the beam patterns for the older 8 in. signals, as is shown in the laboratory test results in Figure 34.

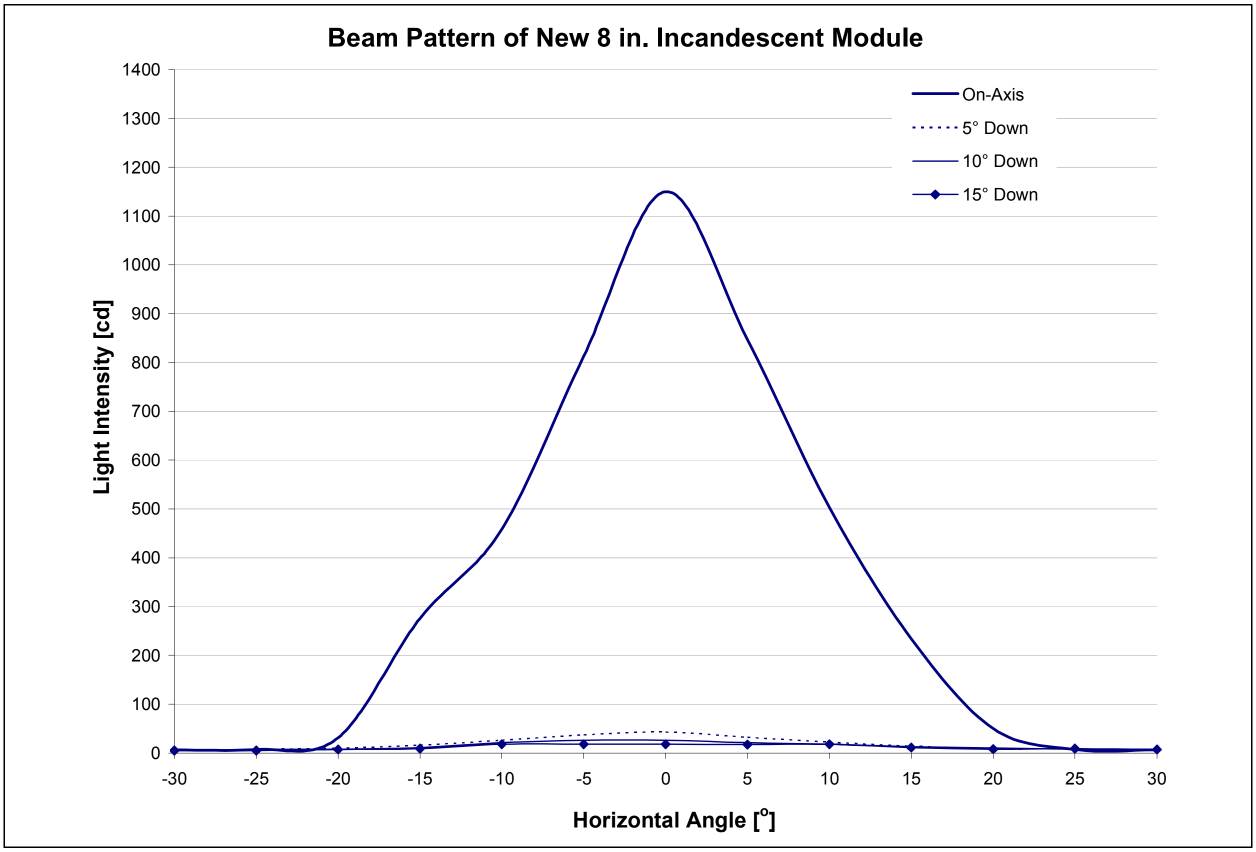


Figure 34 Beam Pattern for the New 8 in. Incandescent Signal (30-15° roundel, 18 W bulb, operating at 10.5 V)

Table 17 – Measured Luminous Intensity for New 8 in. Incandescent Signal

	30° L	*25° L*	*20° L*	*15° L*	*10° L*	*5° L*	*0°*	*5° R*	*10° R*	*15° R*	*20° R*	*25° R*	*30° R*
0°	6	7	31	276	458	813	1150	847	503	234	50	7	6
5° D	7	7	10	16	26	37	43	32	22	14	9	8	6
10° D	6	7	8	11	21	26	26	21	18	13	10	8	7
15° D	5	5	7	9	18	18	18	17	18	11	8	9	7

The apparatus used to mount the incandescent lights was also modified so that the signals were mounted on the same structures used at railway crossings, which allowed the two signals to be aligned more accurately (see Figure 35). Alignment of signals was done as follows: signals were turned on steady, the lenses were folded down, and the modules were rotated left and right until the brightest spot was observed by an individual at the 300 yd. berm in lane 3. When the brightest spot was found in the horizontal plane, the light was tilted up and down to find the overall brightest spot. Handheld radios were used to communicate with the target individual at the 300 yd. berm.

Figure 35 Mounting Arrangement for New Incandescent Modules

The five pairs of signals were wired to one Union Switch & Signal Flasher. Two 12 V batteries were used to power the flasher and five pairs of lights. One 12 V battery was connected through a dropping resistor to supply 10.5 V to the flasher and three pairs of lights. The three pairs of lights powered at 10.5 V were LED #3, LED #4 and incandescent. The other two pairs, LED #1 and LED #2, were powered at 12 V from the second 12 V battery. The same flash rate was applied to all the lights.

Evaluation sheets were modified to include specific questions about brightness, flashing and colour of lights so that numbered rating of lights would only describe brightness and not other factors.

7.2.2 Focus Group Description

The focus group ranged in age from 20 to 84. Table 18 and Table 19 describe participants used in the daytime and nighttime focus groups.

Table 18 – Daytime Focus Group Description

Observer	1	2	3	4	5	6	7	8
Age	84	77	53	46	37	29	22	20
Gender	M	M	M	F	F	F	M	M

Table 19 – Nighttime Focus Group Description

Observer	1	2	3	4	5
Age	53	46	29	22	20
Gender	M	F	F	M	M

Figure 36 The Focus Group Assessing Signal, Field Test #2

7.2.3 Evaluation Protocol

The second field test took place on 16 October 2001 beginning at noon. When cloudy, the sky luminance was between 15,000 and 20,000 lux. When sunny, the sky luminance was between 50,000 and 60,000 lux. Table 20 summarizes the locations from which the signals were observed, and the angles from that location to the incandescent signals.

Table 20 – Summary of Evaluation Points for Field Test #2

Lane	**3**	**7**	**12**	**24**	
	Horizontal Angle (°)				Vertical Angle (°)
50 ft. Berm, below	0	15			18
50 ft. Berm	0	15	30		8
100 yd. Berm	0		19		3.5
200 yd. Berm	0		10	24	1.6
300 yd. Berm	0		6	15	1.1
400 yd. Berm	0			12	1.0
500 yd. Berm	0			8	0.8
600 yd. Berm	0			6	0.7

All observations were completed by 2 pm.

Five evaluators of the original focus group returned to Heal’s Firing Range at 8 pm to evaluate signals at night. Evaluations were made in the same positions as the daytime observations, paying close attention to the lights being too bright on top and in front of the 50 ft. berm. Nighttime observations were completed by 10 pm.

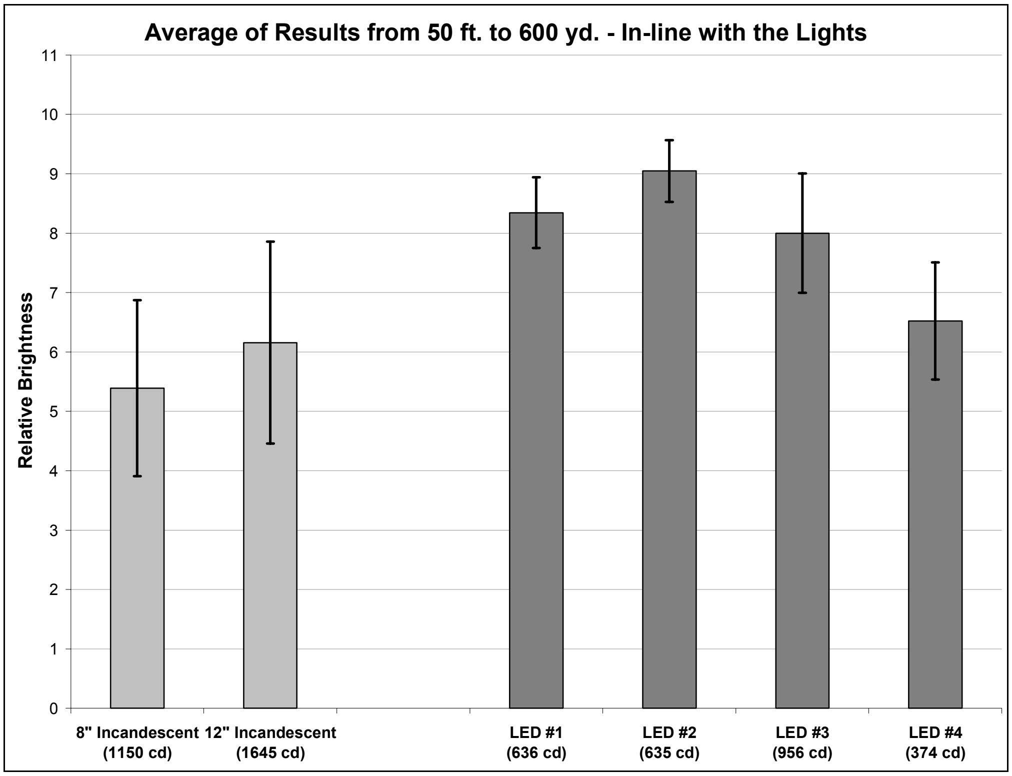
Signals were assessed with the same rating scale as in Field Test #1.

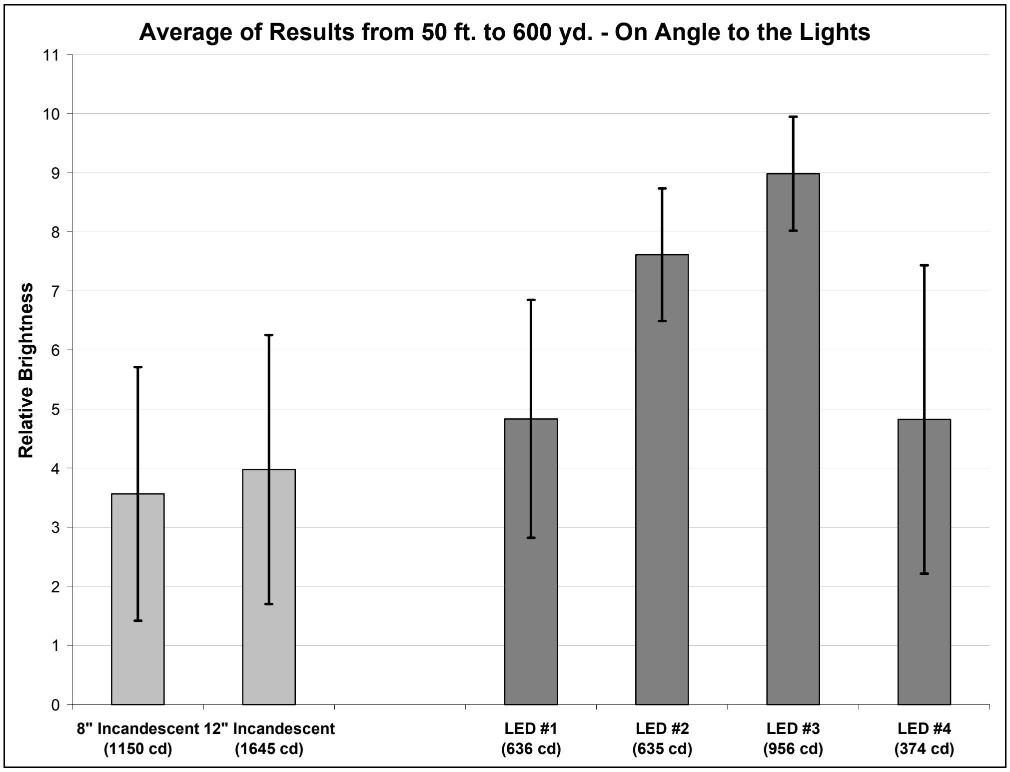
7.2.4 Results of Field Test #2

The following charts present the average and standard deviation of the responses from the focus groups in comparing the five types of signals.

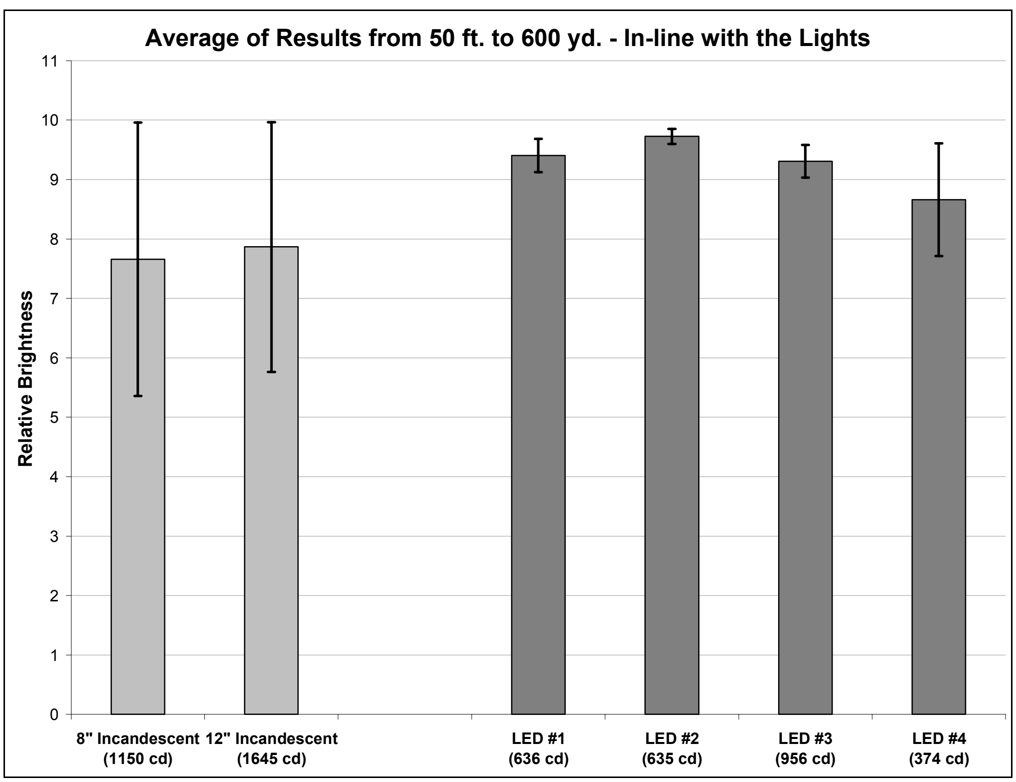
Comparison of LED Signal Modules with Newer Incandescent Lights

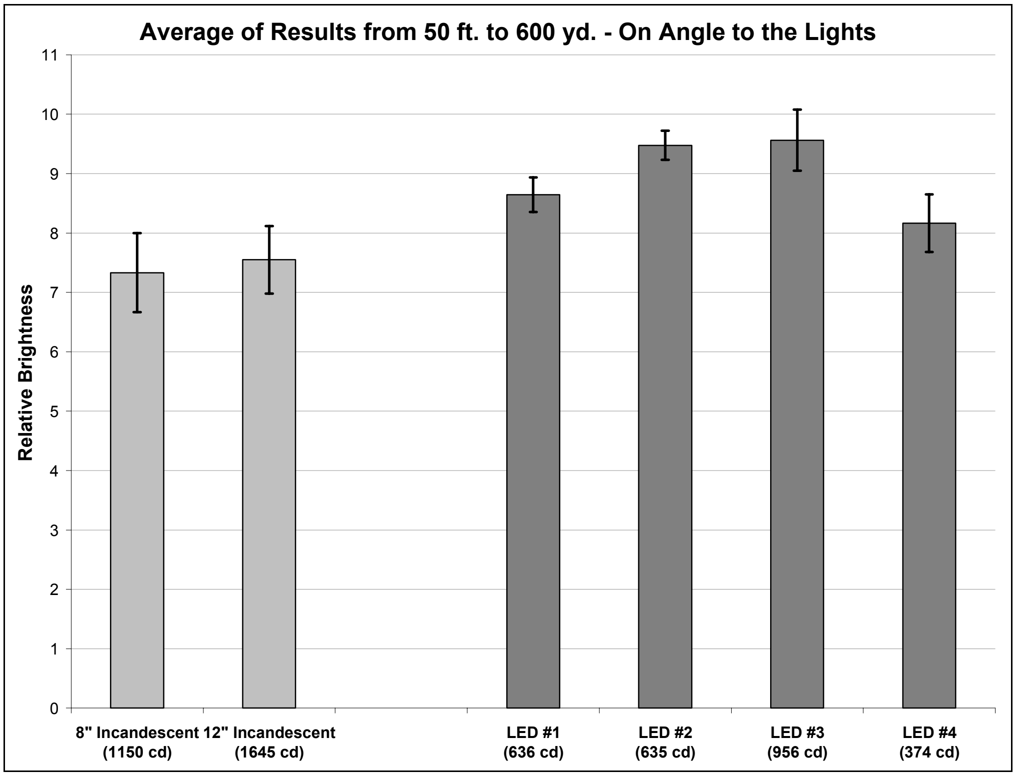
DAYTIME




Average of Results from 50 ft. to 600 yd. - On Angle to the Lights
Relative Brightness
0
1
2
3
4
5
6
7
8
9
10
11
8" Incandescent (1150 cd)
12" Incandescent (1645 cd)
LED #1 (636 cd)
LED #2 (635 cd)
LED #3 (956 cd)
LED #4 (374 cd)

NIGHTTIME


Average of Results from 50 ft. to 600 yd. - In-line with the Lights
Relative Brightness
0
1
2
3
4
5
6
7
8
9
10
11
8" Incandescent (1150 cd)
12" Incandescent (1645 cd)
LED #1 (636 cd)
LED #2 (635 cd)
LED #3 (956 cd)
LED #4 (374 cd)



7.2.5 Conclusion re Field Test #2

The new, and more carefully aligned, incandescent modules improved their performance relative to the LED modules in this second experiment. However, the LED signals consistently outperformed the incandescent signals. During daylight the differences in the two technologies are more significant, particularly on the angle evaluations. At night, the various signals all appear relatively equal in intensity, although the LEDs are still consistently rated higher than the incandescent signals.

LED #4, which has no secondary lens and a circular beam pattern, was not considered to be a satisfactory signal. The problem is evident in the data from the angled observation points in the daylight results. The LED #4 results have a huge standard deviation because of the poor results at some of the observation locations at larger angles to the signal. The decision was made to drop this signal from the next field test since the beam pattern was not broad enough to meet the requirements of a universal beam pattern.

With regard to the issue of being too bright at night, LED #1 and LED #2 were noted as being a little too bright at 50 ft. but acceptable.

7.3 Field Test #3

Having eliminated the round beam pattern in the first two field tests, Field Test #3 was designed to further narrow the recommended beam pattern and luminous intensity requirements. With the brightest lights bordering on being overly bright at night, the band of the signals was reduced to the 400 to 600 cd range. Two of the lights had similar beam patterns resembling traffic lights (LED #1 and #2) and one had a narrow, wider beam (LED #3).

In this experiment, all of the lights were aligned in the same manner using a laser pointing device developed by CN, and the sawhorses used to hold the signal lights were further improved to ensure that each signal head could be individually aimed without disturbing the second signal. All of the lights were aligned on the same target 100 yd. from the signal.

The attendees of the Steering Committee Meeting on April 15-16, 2002 were used to evaluate 3 pairs of LED railway lights, one new style 8 in. incandescent light and one new style 12 in. incandescent light at Heal's Firing Range in Victoria, BC. The lights were aimed at a target located at 100 m and aligned using the aligning tool.

7.3.1 Methodology

The third field experiment set-up was a repeat of the first two, with modifications to improve the alignment of the lights, wiring set-up and evaluation sheets. Instead of the wooden horses used for mounting lights in the first two experiments, new metal horses were used. These horses are stronger and more stable, and the leg height could be individually adjusted. One horse was used for each light; so each signal could be focused and adjusted separately.

The apparatus used to mount the incandescent lights was also strengthened to improve the stability of alignment (see Figure 37).

Figure 37 Modules Mounting Arrangement of Incandescent Lights

Silver coloured insulation sheets were draped over the lane numbers to provide a reflective surface behind the lights. This was done in order to simulate brighter conditions behind the light and to ensure that the backgrounds behind each test light were the same.

Figure 38 Test Set-up with Reflective Sheets Behind the Lights

All of the lights were aligned using the CN-designed laser alignment tool. Each signal was aimed at a reflective target placed in lane 3 at the 100 yd. berm (The target is visible in Figure 38).

Pairs of lights were arranged in the same order as before, except there were only three pairs of LED lights.

- Lane 1 – LED#1
- Lane 2 – LED #2
- Lane 3 – 8 in. and 12 in. Incandescent
- Lane 4 – LED #3

Signals were wired in such a way that the light intensity on some pairs could be switched between 400 cd and 600 cd, while the others could be kept the same.

The four pairs of lights were wired to one Union Switch & Signal Flasher. Two power supplies were used to power the flasher, allowing for independent control of two groups of signals. The same flash rate was applied to all the lights.

The evaluation group was asked to compare the effectiveness of the eight individual lights, rather than treating the signals in pairs as was done before.

7.3.2 Evaluation Protocol

Beginning at 1 pm, 15 April 2002, a focus group of 15 evaluators took part in the third field test. It was raining, with the rain coming down quite hard at the beginning of the test. The rain stopped, but heavy overcast remained, toward the end of the test.

The test consisted of two parts, with the signals having the following luminous intensities for each part:

Table 21 – Light Intensities for Each Pair of Lights

	Pair #1		**Pair #2**		**Pair #3**		**Pair #4**	
	Left	*Right*	*Left*	*Right*	*Left*	*Right*	*Left*	*Right*
Part #1	400 cd	600 cd	400 cd	400 cd	8 inch	12 inch	400 cd	600 cd
Part #2	400 cd	600 cd	600 cd	600 cd	8 inch	12 inch	600 cd	400 cd

The group of 15 was split into two groups of 7 and 8 people each, with one group evaluating at half of the observation points for Part #1 of the test, and the other half for Part #2, and the second group evaluating the remaining observation points. The evaluations were completed by 4 pm. No observations were taken at night, since the previous field tests had shown that the luminous intensity was much less of a factor at night.

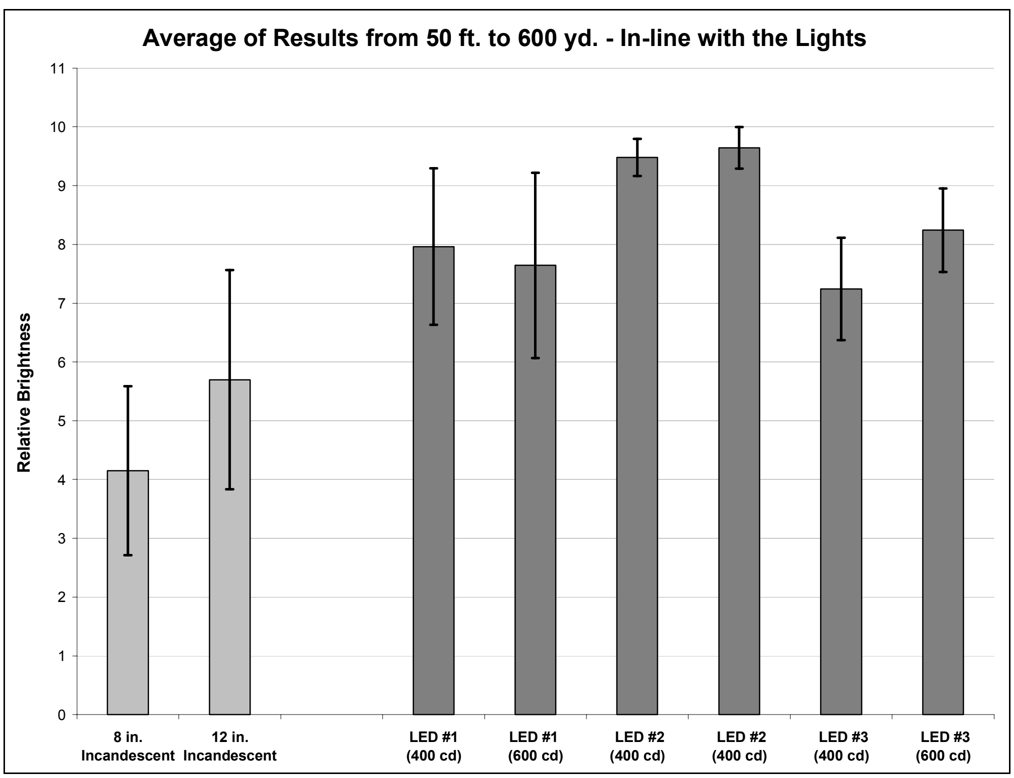
Table 22 – Summary of Evaluation Points for Field Test #3

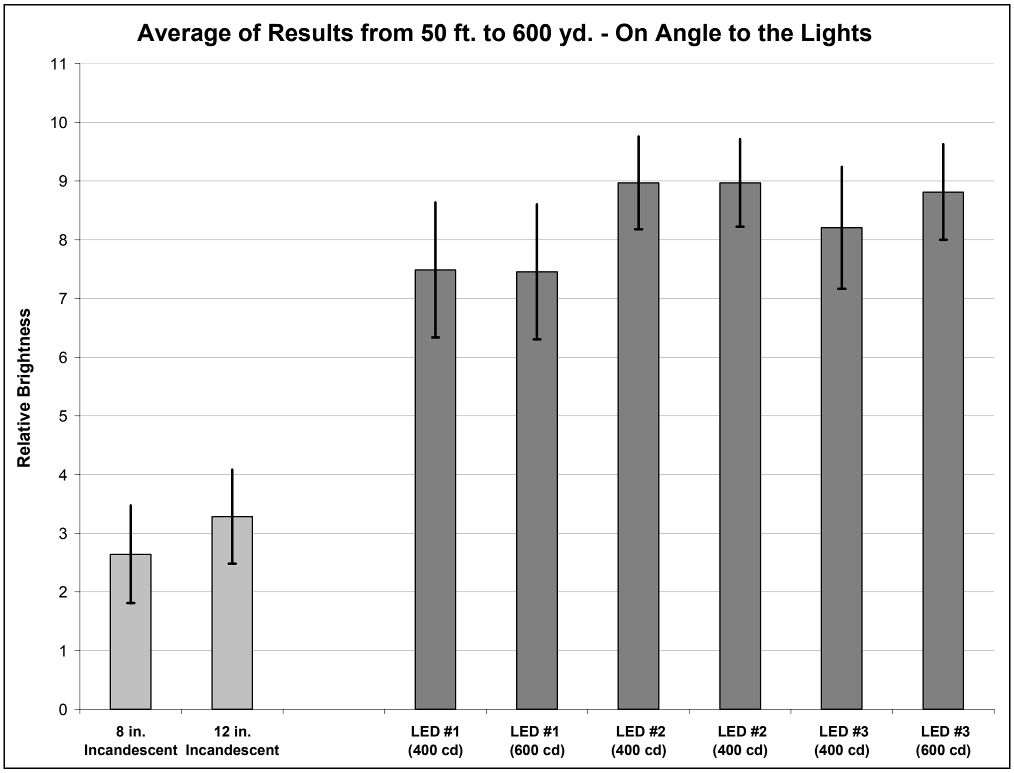
Lane	**3**	**7**	**12**	**24**	
	Horizontal Angle (°)				Vertical Angle (°)
50 ft. Berm, below	0		30		18
50 ft. Berm	0		30		9
100 yd. Berm	0		19		3.5
200 yd. Berm	0			24	1.6
300 yd. Berm	0			15	1.1
400 yd. Berm	0			12	1.0
500 yd. Berm	0			8	0.8
600 yd. Berm	0			6	0.7

Figure 39 Focus Group Walking Toward Another Observation Point

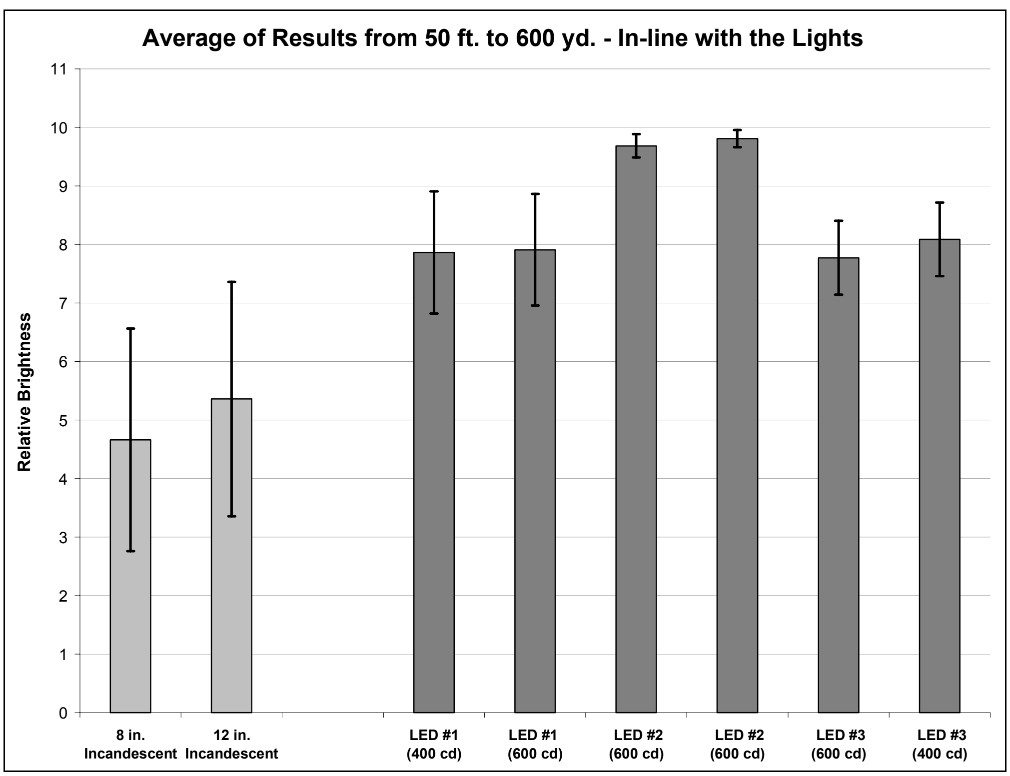
7.3.3 Results of the Field Test #3

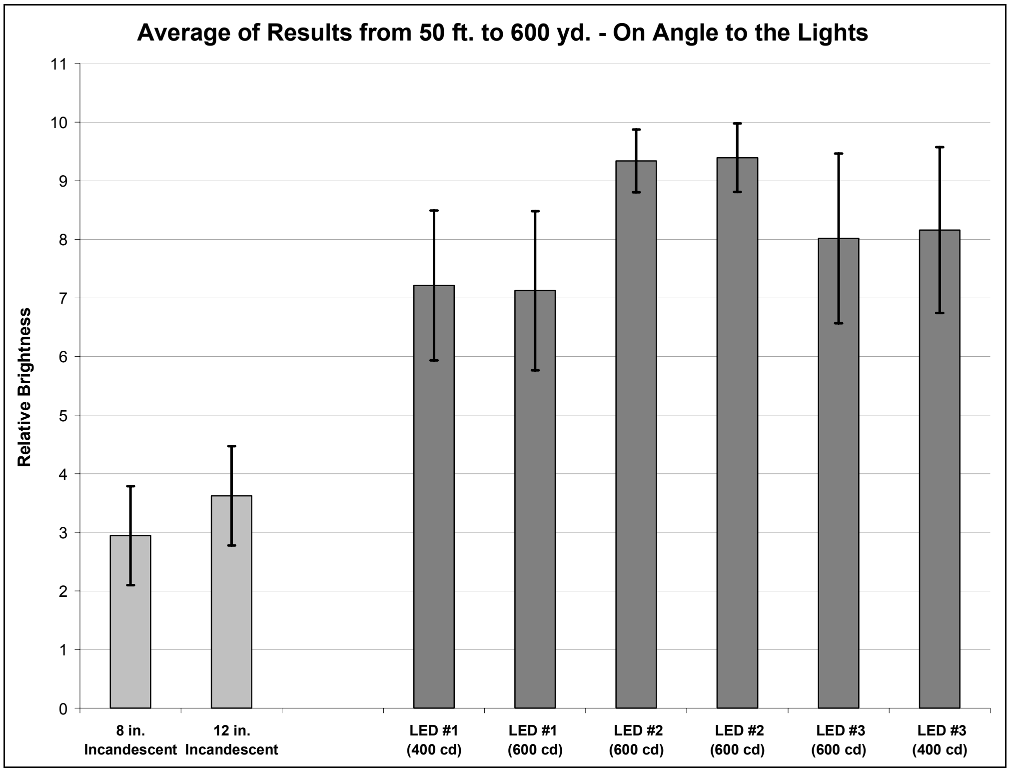
PART #1




Average of Results from 50 ft. to 600 yd. - On Angle to the Lights
Relative Brightness
0
1
2
3
4
5
6
7
8
9
10
11
8 in. Incandescent
12 in. Incandescent
LED #1 (400 cd)
LED #1 (600 cd)
LED #2 (400 cd)
LED #2 (400 cd)
LED #3 (400 cd)
LED #3 (600 cd)

PART #2


Average of Results from 50 ft. to 600 yd. - In-line with the Lights
Relative Brightness
0
1
2
3
4
5
6
7
8
9
10
11
8 in. Incandescent
12 in. Incandescent
LED #1 (400 cd)
LED #1 (600 cd)
LED #2 (600 cd)
LED #2 (600 cd)
LED #3 (600 cd)
LED #3 (400 cd)



7.3.4 Conclusion re Field Test #3

The results again clearly show the superior performance of the LED signals over the incandescent signals. LED signals at both 400 and 600 cd performed better than incandescent lights when viewed from directly in front, and were far superior when viewed on an angle.

The difference between LED signal lights operating at 400 cd and 600 cd was not statistically significant.

With the proposed luminous intensity requirement narrowed to the range of 400 cd to 600 cd, and since the focus group was unable to distinguish between these two luminous intensities in the field, a laboratory test was recommended to see if the focus group could distinguish between the two luminous intensity under controlled conditions in the laboratory.

7.4 Laboratory Comparison of 400 cd and 600 cd

The focus group was shown an LED railway crossing light producing 600 cd in the optics laboratory, which is a narrow black room. The group was then asked to step out of the laboratory and return repeatedly while the LED module was toggled randomly between 600 cd and 400 cd. Upon each trip into the laboratory, the group was asked to identify whether the module was producing 600 cd or 400 cd output. Five tests were done with the group leaving the room and returning to assess the light output, and three were done with the group staying in the laboratory but looking down as the light was adjusted. A score of 50% would have represented random choice by the focus group, since there were only two possible answers on the test sheet. The results of this experiment are summarized in Table 23.

Table 23 – Laboratory Test: Focus Group Leaving and Returning to Laboratory

Trial Number	Number of Correct Answers	Correct Answer
Training observation		600 cd
1	8/14	600 cd
2	10/14	400 cd
3	12/14	400 cd
4	13/14	600 cd
5	11/14	400 cd
6	8/14	400 cd
7	4/14	600 cd
8	10/14	400 cd

7.4.1 Conclusion re Laboratory Comparison

Out of 112 tests comparing 400 cd and 600 cd, 78 (70%) were identified correctly. While this is above the 50% random response level, it does show that 400 cd and 600 cd are perceived very similarly by the human eye, even under very controlled conditions. The results demonstrate the logarithmic response of the eye to luminous intensity, which predicts that the difference in perceived luminous intensity is about 7%, rather than the 50% difference that would be perceived if the eye responded linearly to changes in luminous intensity.

8. STAKEHOLDER FEEDBACK

As a key element of this project, an intensive effort was made to canvas the stakeholders involved in highway-railway crossing safety. These stakeholders included the railways (at several levels), Canadian and U.S. regulatory officials at the provincial/state and federal level for both highways and railways, manufacturers of LED signal modules, distributors of railway signals, a lawyer involved in railway crossing litigation, and academics with relevant research interests. A list of stakeholders with whom we consulted is included as Appendix C: The transcripts from many of these interviews are available on the web at railwaycrossings.com.

Some of the more general comments that indicate the flavour of the discussions that took place are summarized below. Other more detailed feedback that involved operational issues regarding the signal lights has been incorporated into the standard and/or the purchasing specification.

8.1 General Comments on Incandescent Signals

It is a common problem for incandescent lights to go out of focus or out of alignment, with severe consequences for the perceived brightness by the driver. Focusing and alignment are a major issue in the maintenance of signals at grade crossings, and all people contacted stated that the most important contribution that LED technology could make would be to eliminate the focusing requirement and reduce the alignment requirements in the maintenance of the signal modules.

8.2 General Comments on Setting an LED Signal Specification

- LEDs are better due to their colour attributes.
- LEDs are better due to their fast rise time.
- Incandescent bulbs were always out of alignment/focus/dirty mirror and didn’t meet the 1600 cd specification after they were in the field for a while.
- 1500 ft. visibility was the original specification, and you do not need 1600 cd to get 1500 ft. of visibility.
- 1500 ft. was too much anyway: the lights are aimed at 1000 ft. Should look at braking distance.
- The whole spec was based on what could be done, not what needed to be done.
- The incandescent standard was high for on-axis brightness, but the beam pattern was very narrow.
- Use the highway specification: why do we need a separate specification for railways?
- Caution with using highway specification: trains are less forgiving than highway intersections: no yellow warning light, no crossing traffic to indicate danger.
- Brighter is better: don’t compromise brightness to suit LEDs.

From stakeholders comments, several key principles emerged:

- Stakeholders strongly supported a broader beam pattern, with a lowering of the peak intensity, rather than the narrow beam pattern with a spot of high intensity as required in the past, as long as the overall light output was improved.
- Stakeholders strongly supported a standard that required that the luminous intensity be maintained over the expected life of the signal, rather than an initial specification that included an allowance for degradation over time.

- Stakeholders were broadly supportive of using this opportunity to bring the railway crossing standard into line with traffic light requirements.

These principles helped establish the principles by which the luminous intensity standard was eventually decided.

9. PHOTOMETRIC REQUIREMENTS

We have reviewed the existing railway and highway standards, studied the literature on human factors relevant to the perception of LED signals, computed the required luminous intensity to warn drivers at the necessary braking distance, reviewed the scientific literature on recommended traffic light intensities, conducted a series of laboratory and field experiments, and consulted extensively with stakeholders. This body of work will now be used to set the photometric requirements for LED signal lights.

9.1 Principles/Goals in Setting Photometric Requirements

The following principles and goals have been established from stakeholder consultation: that the standard must …

- be a measurable, quantifiable standard that can be applied throughout the life of the signal;
- be based on drivers' requirements and human factors considerations, not on the capabilities of the technology;
- be confirmed with laboratory and field testing;
- be the same specification for 8 in. and 12 in. lights;
- be a universal specification for front, back and lane lighting to avoid requiring different signal modules for each location;
- define a broad beam pattern so alignment is not critical and standard traffic light structures can be used;
- equal or exceed AREMA range requirements as expressed in the latest version of their recommended specifications; and
- meet or exceed the most demanding high-speed, wide-angle traffic light specifications.

Using these principles and applying them to the results of work to date leads to the following conclusions regarding the photometric requirements.

9.2 Review of Standards

Since we have agreed that the standard for the crossing signals cannot be less than the most demanding traffic light requirements, we can derive from the standards a minimum luminous intensity that will be acceptable. The traffic light standards vary in how they deal with degradation over time once the signals are installed. The North American standard (339 cd off axis) is the most rigorous in this regard, requiring that the intensity be maintained over the three year warrantee period (although there is no mention of what happens after that). The European standard (400 cd on axis) allows for a 'nominal' reduction after installation, without specifying what 'nominal' means. The Australian standard is higher (600 cd on axis), but allows for a 25% reduction after installation.

We conclude that a 400 cd requirement that must be maintained throughout the life of the signal module is the lowest level of light output that can be tolerated if we stay with the principle of equivalence to the most demanding traffic light specification.

With regard to the beam pattern, this principle of equivalence to traffic light standards also defines the shape of the beam pattern. As we have discussed, the shape of the beam in the traditional railway incandescent bulb is narrow, particularly in the vertical direction. The 30-15° roundel has a 15:1 ratio of horizontal to vertical dimensions. The 70° roundel has no requirement for any light in the vertical direction, so the horizontal to vertical ratio is essentially infinity. For traffic lights, the beam pattern is much broader and so, based on the principles above, the broader beam pattern used in traffic lights is the minimum that can be allowed in the LED specification.

9.3 Discussion of Human Factors

Our review of human factors considerations indicates that LED signal modules can be expected to outperform incandescent signals with the same luminous intensity due to two inherent advantages:

1) LED signals produce a pure red signal rather than a filtered white light, which is more conspicuous to the human eye.
2) LED signals can turn on and off instantaneously (as long as this characteristic is not compromised by the LED power supply).

Accordingly, if the proposed standard is based on the body of literature and experience from incandescent signal lights, then LED signals can be expected to provide an additional margin of conspicuity.

The review of human factors also provides us with an important upper limit on the luminous intensity. Intensities in the range of 1000 cd or more, when viewed directly at close range (33 m) at night, can be too intense for drivers. Since back lights are frequently aimed at this range, and since our principle is that the same signal will be used for back lights as for front lights, this consideration places an upper limit on the desired luminous intensity of approximately 1000 cd.

9.4 Discussion of Driver Requirements

The review of driver requirements established that the highest speed roads require that the driver be warned of a crossing at about 330 m. Algorithms from the scientific literature for traffic light intensities, railway signal intensities, and marine navigation light intensities allow us to calculate the required intensity of signal lights to achieve this range. The minimum light output to achieve this range is approximately 100 cd, which is well below the minimum that we have already established, and would not provide any margin for driver distraction. The highway algorithm, which attempts to account for driver distraction, results in a recommendation of 4000 cd, which is well above the maximum that can be tolerated at night. Driver requirements, then, do not narrow down the range of the standard, which, based on considerations discussed to date, could range from 400 cd to 1000 cd.

9.5 Discussion of Scientific Literature

The scientific literature that has reviewed the issue of recommended luminous intensity for high speed traffic lights has produced recommendations in the range of 300 cd to 800 cd. Since we have already set a minimum of 400 cd, the body of scientific literature does narrow the range somewhat to within 400 cd to 800 cd.

9.6 Discussion of Field Tests

In order to further narrow down the recommended standard, the laboratory and field work showed that 400 cd LED signals with the broad beam of traffic lights clearly outperformed new, carefully aligned 8 in. (200 mm) and 12 in. (300 mm) incandescent signals. Increasing the luminous intensity from 400 cd to 600 cd was not statistically significant in the field. Going as high as 800 cd in the standard was not deemed to be desirable, since the standard is to be a 'maintained' standard, which means that manufacturers must build in some additional intensity to account for degradation over time once the light is installed. An 800 cd signal would mean an initial intensity of 1000 cd or more, which would be overly bright at night.

The laboratory and field results indicate that a minimum, rigorous, maintained standard of 400 cd with a broad beam pattern will greatly improve conspicuity of signal lights, particularly at angles as the driver approaches.

The field testing also supports the traffic light beam pattern, rather than a round beam pattern, which was found to be inferior.

9.7 Stakeholder Consultation

There is clearly a balance between requiring a high light output over a narrow beam, or a lower light output over a larger beam. There are two issues with a narrow beam of high intensity: deciding where to aim it, and then aiming it accurately. Railway engineers indicate that there are many problems experienced in the field with alignment and focus of very narrow beams; they prefer to spread the light over a wider beam and sacrifice some of the intensity. The important requirement is that the total light output not be decreased.

Following this line of reasoning – that the LED specification should improve on the optical power produced by the incandescent lights but distribute this optical power more broadly – a 400 cd LED signal with a broad beam pattern as per North American high-speed traffic lights (or the widest angle European traffic lights) produces about three times the total luminous intensity of a conventional incandescent signal with a narrow beam.

9.8 Proposed Photometric Standard

The research and testing described in this report lead us to conclude that the minimum luminous intensity and beam pattern that should be required of LED signal modules should be a minimum luminous intensity, on axis, of 400 cd, and a beam pattern of a high-speed, wide-angle traffic light specified every 5° out to an angle of 30° each side of the signal, and downwards 20°.

The proposed photometric standard is as follows:

"When LED signal modules are in use at a highway-railway grade crossing, they shall, at all times and under all normal operational conditions, meet the minimum luminous intensity values shown in Table 24."

Table 24 – Minimum Luminous Intensity (cd) over Temperature and Lifetime

	30° L	*25° L*	*20° L*	*15° L*	*10° L*	*5° L*	*0°*	*5° R*	*10° R*	*15° R*	*20° R*	*25° R*	*30° R*
0°	15	40	75	150	250	375	400	375	250	150	75	40	15
5° D	15	40	75	150	250	325	350	325	250	150	75	40	15
10° D	15	35	60	85	110	125	130	125	110	85	60	35	15
15° D	15	20	25	30	35	40	45	40	35	30	25	20	15
20° D	10	15	15	15	15	15	15	15	15	15	15	15	10

9.9 Detailed Comparison with Traffic Light Photometric Standards

The details of the beam pattern are drawn from careful comparisons with traffic light standards to ensure that the standard meets or exceeds North American and European traffic standards at all of the specified measurement angles. This comparison is complicated by the fact that the North American standard and the European standard do not specify the light output at the same angles, so it is necessary to interpolate. Table 25 shows that, at each specified angle, the proposed standard meets or exceeds the requirements for the high-speed, wide-angle traffic lights for both North America and Europe.

In order to visualize the beam patterns, and compare them to each other and to incandescent railway specifications, the three-dimensional graphs in Figure 40 show the shapes of the various beam patterns.

The two-dimensional graphs in Figure 41 compare the proposed standard with traffic light specifications from North America, Europe, Australia, and the CIE recommendations that are referred to in some publications. In making these comparisons, it is important to keep in mind that the proposed standard and the North American standard are ‘maintained’ standards designed for LED signals, whereas the European, Australian, and CIE standards are initial standards for incandescent lights that include a margin for deterioration over time and temperature that is appropriate for incandescent bulbs.

Table 25 – Comparison Between Proposed Photometric Standard and ITE/European Traffic Light Beam Patterns

	30°R/L	***27.5°R/L***	***25°R/L***	***22.5°R/L***	***20°R/L***	***17.5°R/L***	***15°R/L***	***12.5°R/L***	***10°R/L***	***7.5°R/L***	***5°R/L***	***2.5°R/L***	***0°***
0°	4 15 ✓		40		12 75 ✓		150		220 250 ✓		340 375 ✓		400 400 ✓
2.5° D						**77** 113 ✓		**141** 200 ✓		**251** 300 ✓		**339** 363 ✓	
3° D											300 345 ✓		320 370 ✓
5° D	15		40		75		150		140 250 ✓		325		240 350 ✓
7.5° D		**16** 26 ✓		**38** 53 ✓		**89** 93 ✓		**145** 149 ✓		**202** 203 ✓		**226** 233 ✓	
10° D	15		35		32 60 ✓		85		110		125		120 130 ✓
12.5° D		**16** 21 ✓		**22** 35 ✓		**34** 50 ✓		**44** 65 ✓		**48** 78 ✓		**50** 85 ✓	
15° D	15		20		25		30		35		40		45
17.5° D		**16** 15 ✓		**20** 19 ✓		**22** 21 ✓		**22** 24 ✓		**22** 26 ✓		**22** 29 ✓	
20° D	8 10 ✓		15		15		15		15		15		8 15 ✓

Where : ITE = **BOLD**
European Standard = UNDERLINED
TC Standard 400 cd = *ITALIC*
Interpolated Values from Proposed Standard = BLACK

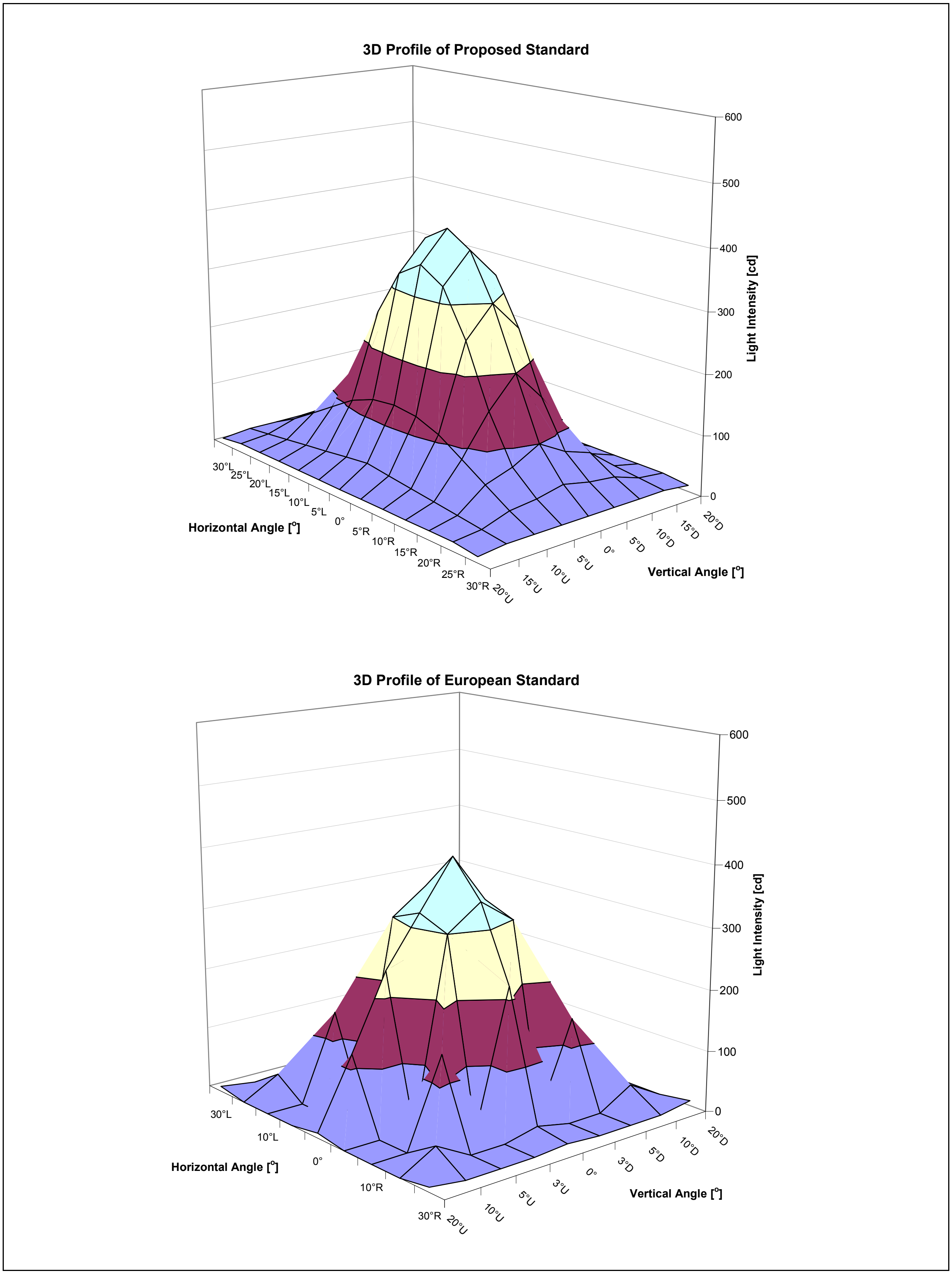


Figure 40 Three-Dimensional Graphs of Different Standards

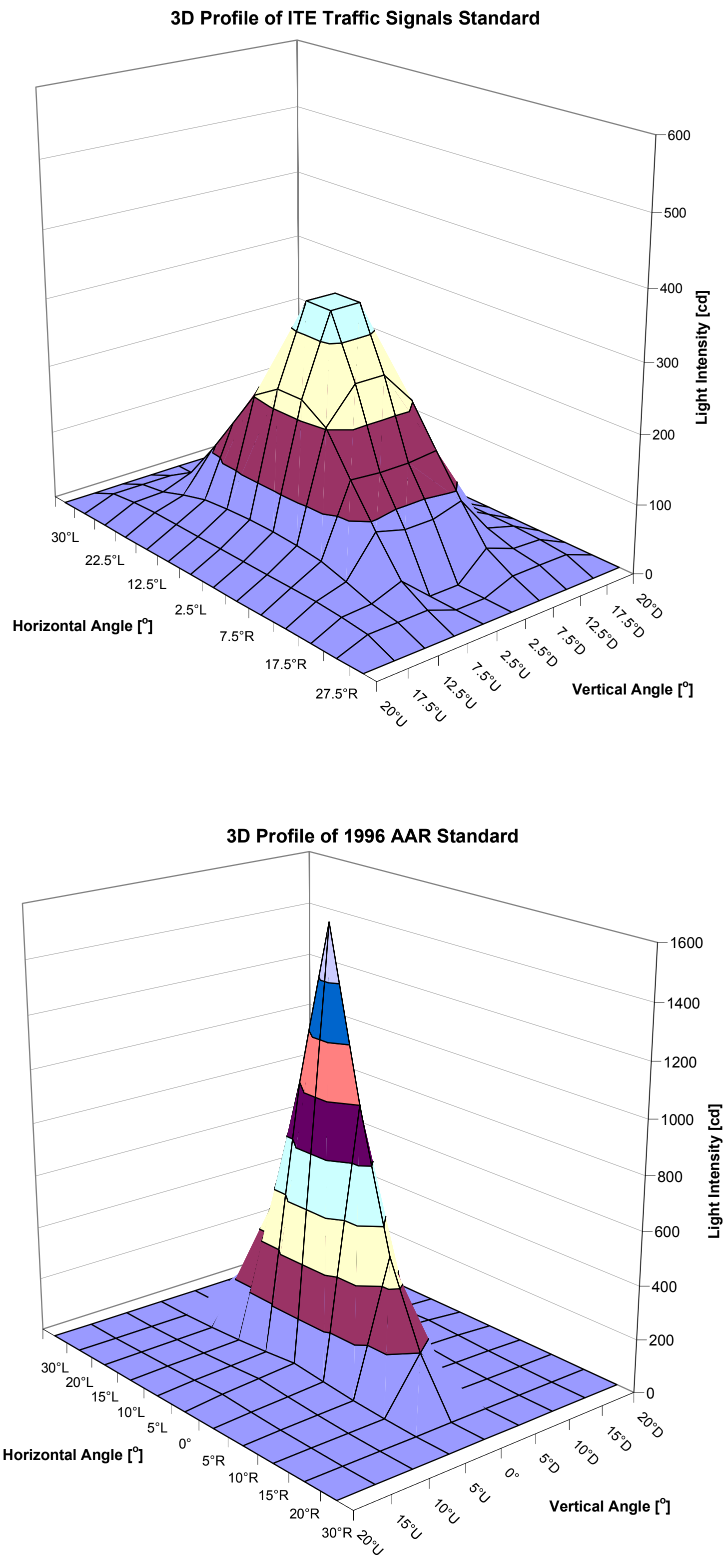


Figure 40 Three-Dimensional Graphs of Different Standards (cont.)

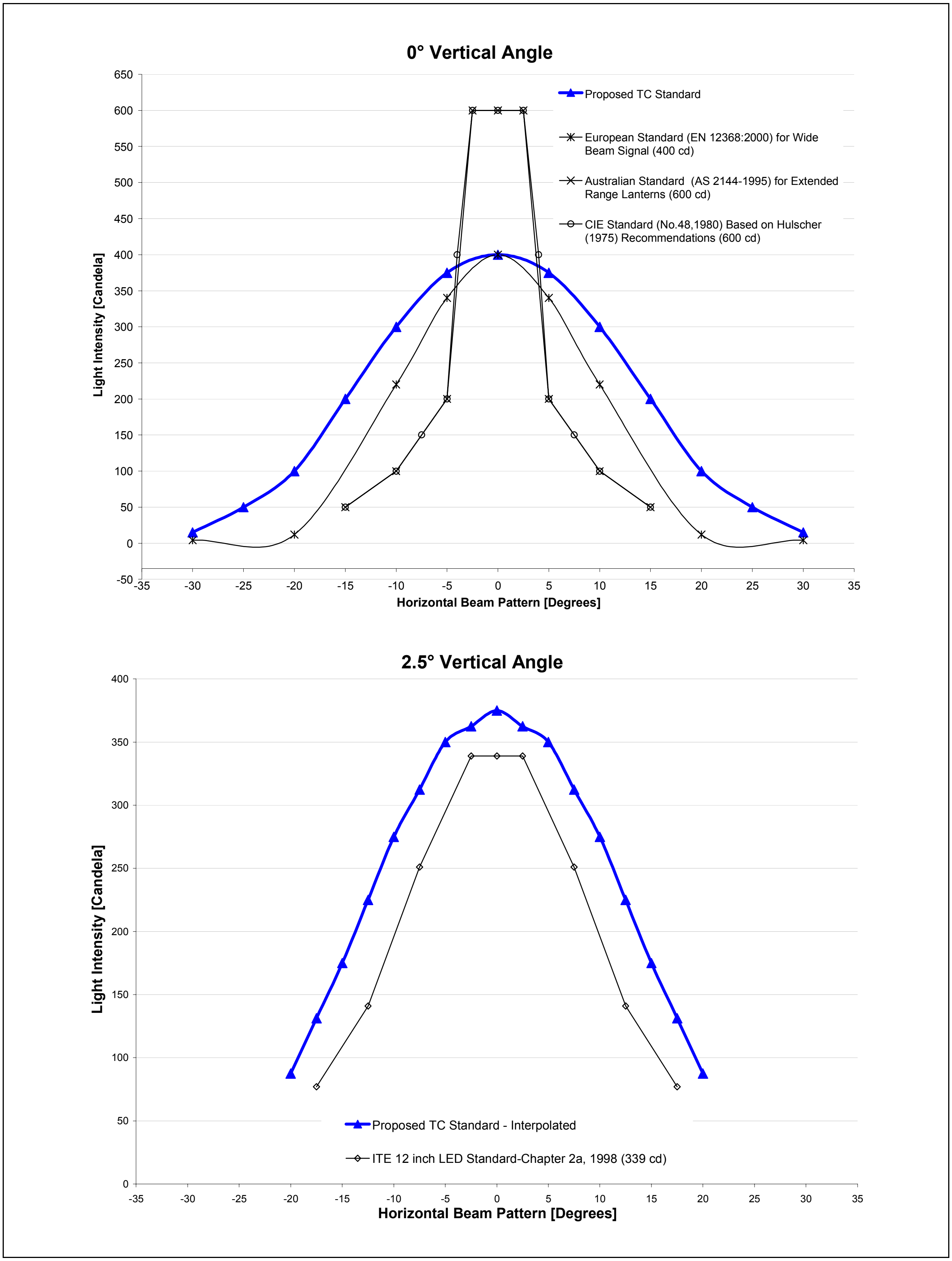


Figure 41 Comparison Between Proposed Photometric Requirements and Different Traffic Light Photometric Standards

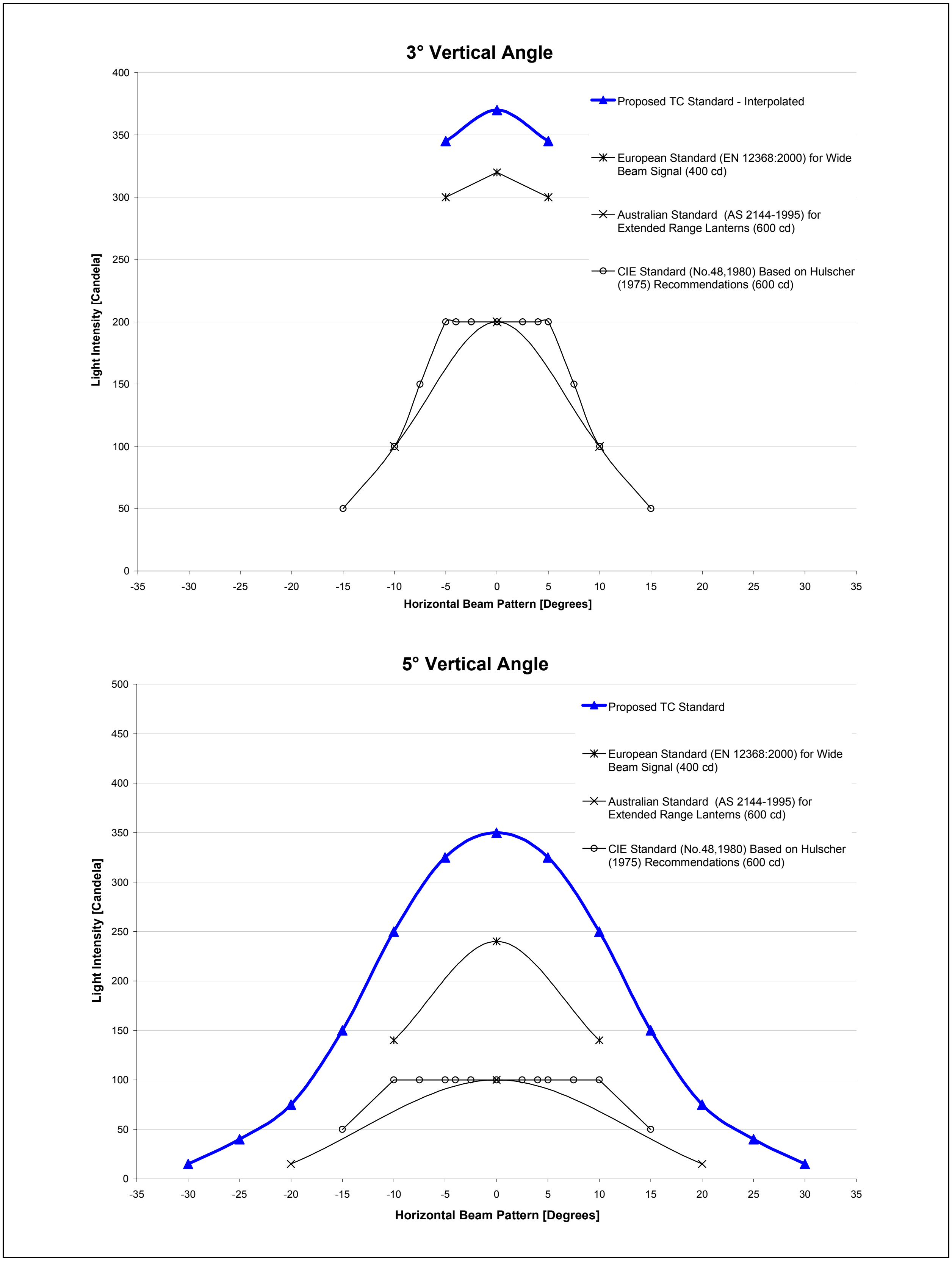
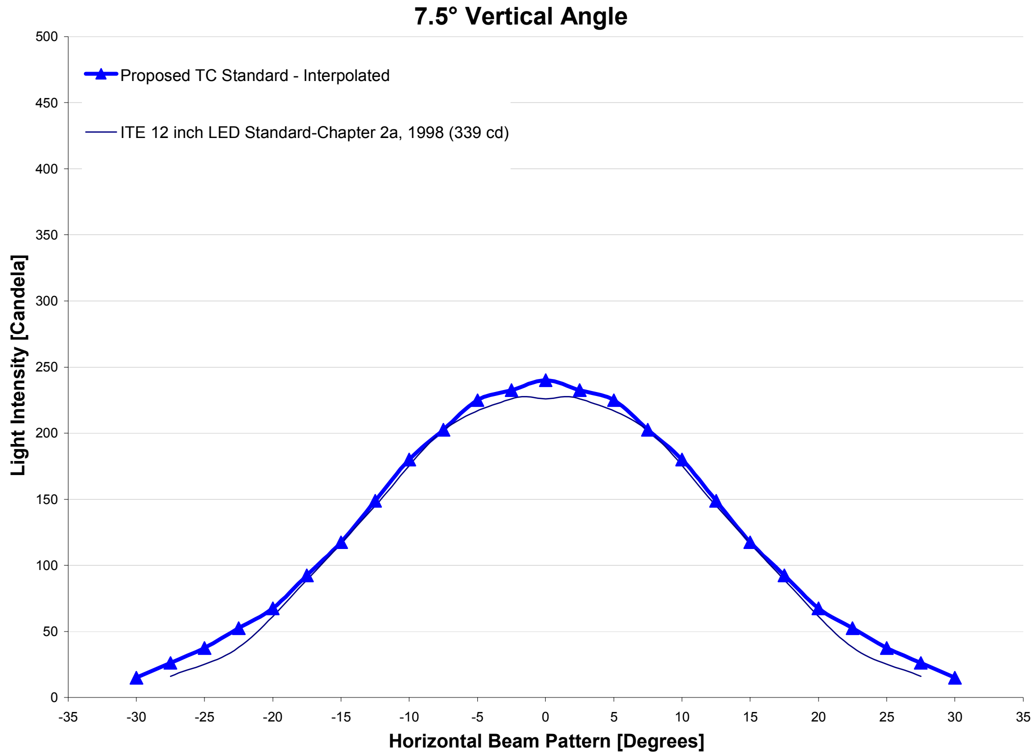


Figure 41 Comparison Between Proposed Photometric Requirements and Different Traffic Light Photometric Standards (cont.)



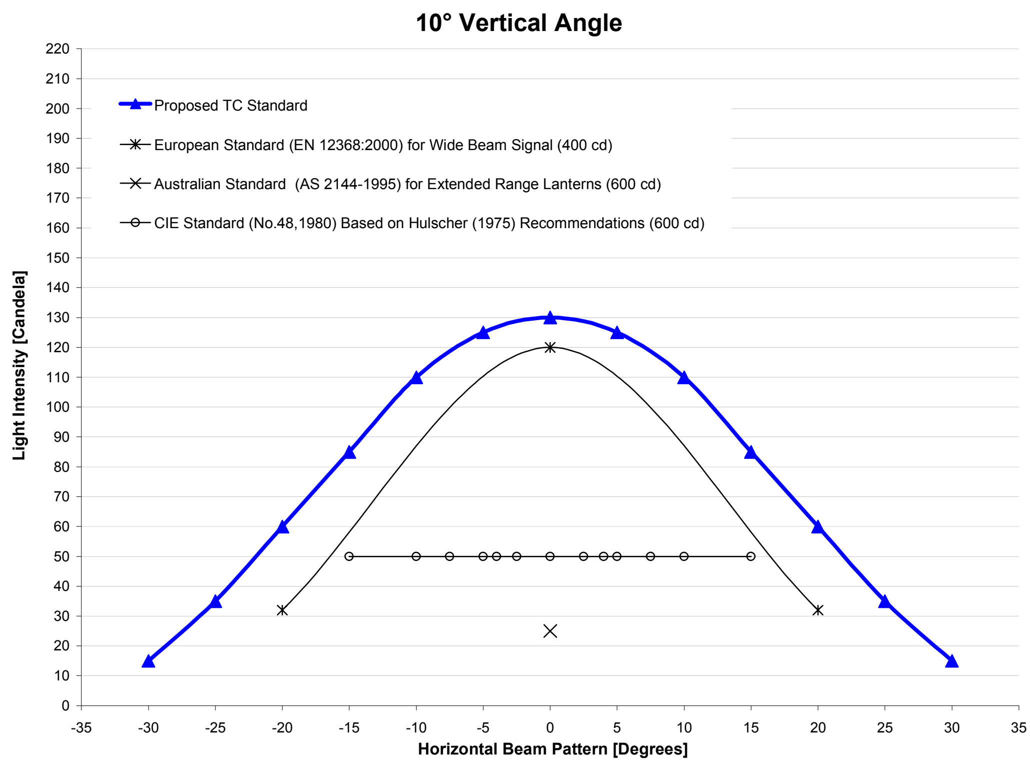


Figure 41 Comparison Between Proposed Photometric Requirements and Different Traffic Light Photometric Standards (cont.)

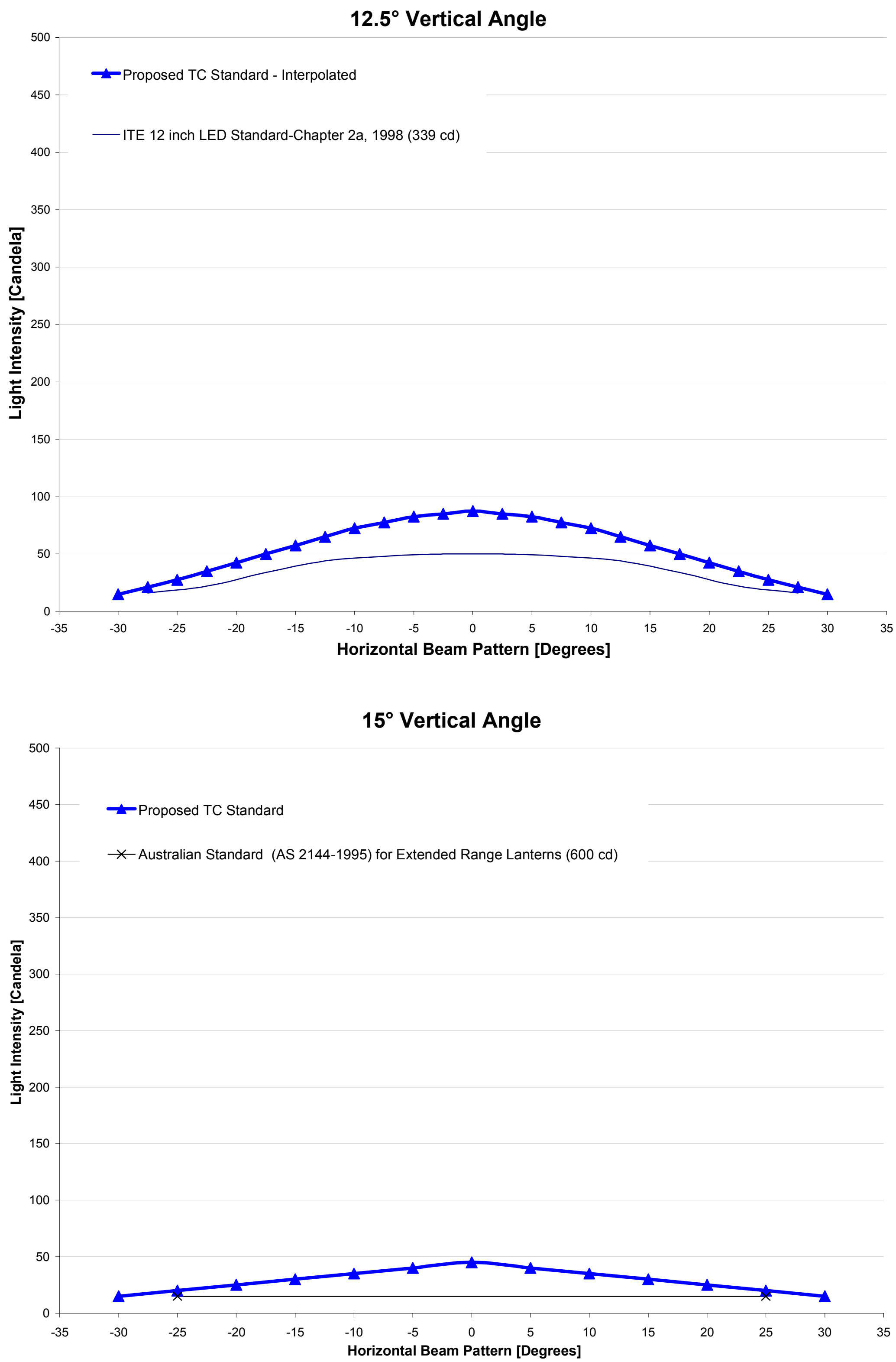


Figure 41 Comparison Between Proposed Photometric Requirements and Different Traffic Light Photometric Standards (cont.)

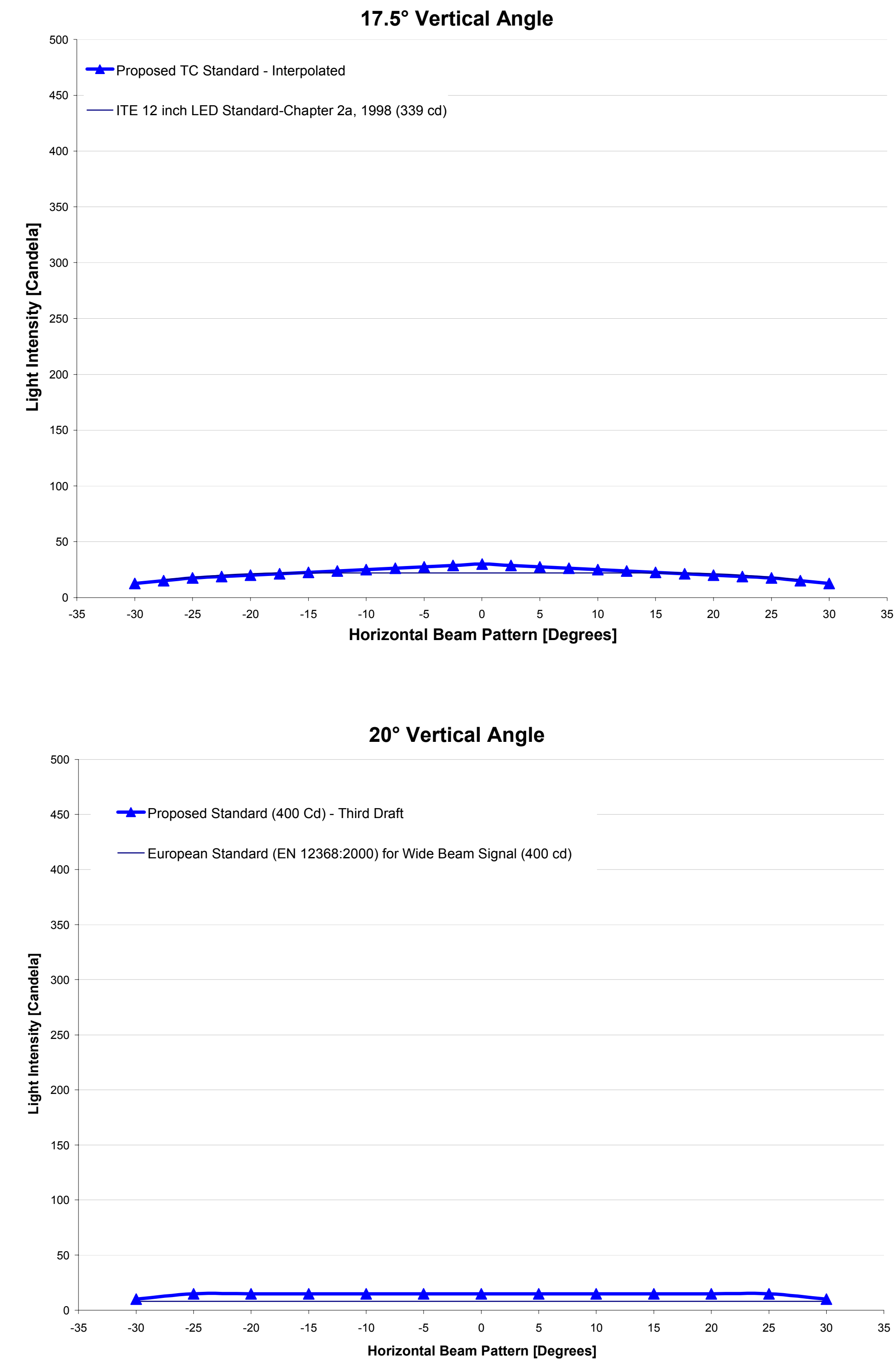


Figure 41 Comparison Between Proposed Photometric Requirements and Different Traffic Light Photometric Standards (cont.)

9.10 Detailed Comparison with Previous Railway Photometric Standards

The graphs in Figure 42 compare various railway photometric standards with the proposed standards. The most recent AREMA standards are not included, since they are specified as a visible range, not in candela, and so are difficult to compare. It is important to remember that the previous railway standards are initial standards at the nominal operating voltage, and that the actual output of the incandescent signals would be affected by the actual operating voltage, by aging of the bulb, by misalignment of the bulb in the focal point of the parabolic mirror, and by aging of the mirror surface.

9.11 Comparison with Beam Patterns from Sample LED Signal Modules

The graphs in Figure 43 compare four sample LED signals, and an 8 in. incandescent signal, with the proposed standard. The results show that, at room temperature and an applied voltage of 10.5 V, two of the four LED lights meet the proposed standard without difficulty. The incandescent light doesn't meet the standard except on-axis; its beam is much too narrow.

The results show that the proposed standard is not unreasonable, and that LED signals using traffic light lenses with adapted power supplies are able to meet the beam pattern requirements.

9.12 Chromaticity Requirements

Both the highway and railway regulations rely on International Commission on Illumination (CIE) methodology to describe the chromaticity of signals. However, the AREMA specifications (AREMA Manual Part 7.1.10) allow a slightly broader range of colour than the Institute of Transportation Engineers (ITE) specifications for highway signals in North America (ITE, 1998), and the CIE specifications for traffic lights in Europe (Pub. No. CIE 79, 1988), as shown in Table 26.

In order to provide consistent colour to drivers, and to use the more rigorous specification of colour, we recommend that the chromaticity requirements of the ITE specifications be adopted. All of the sample LED modules tested used LEDs that met the ITE chromaticity requirement.

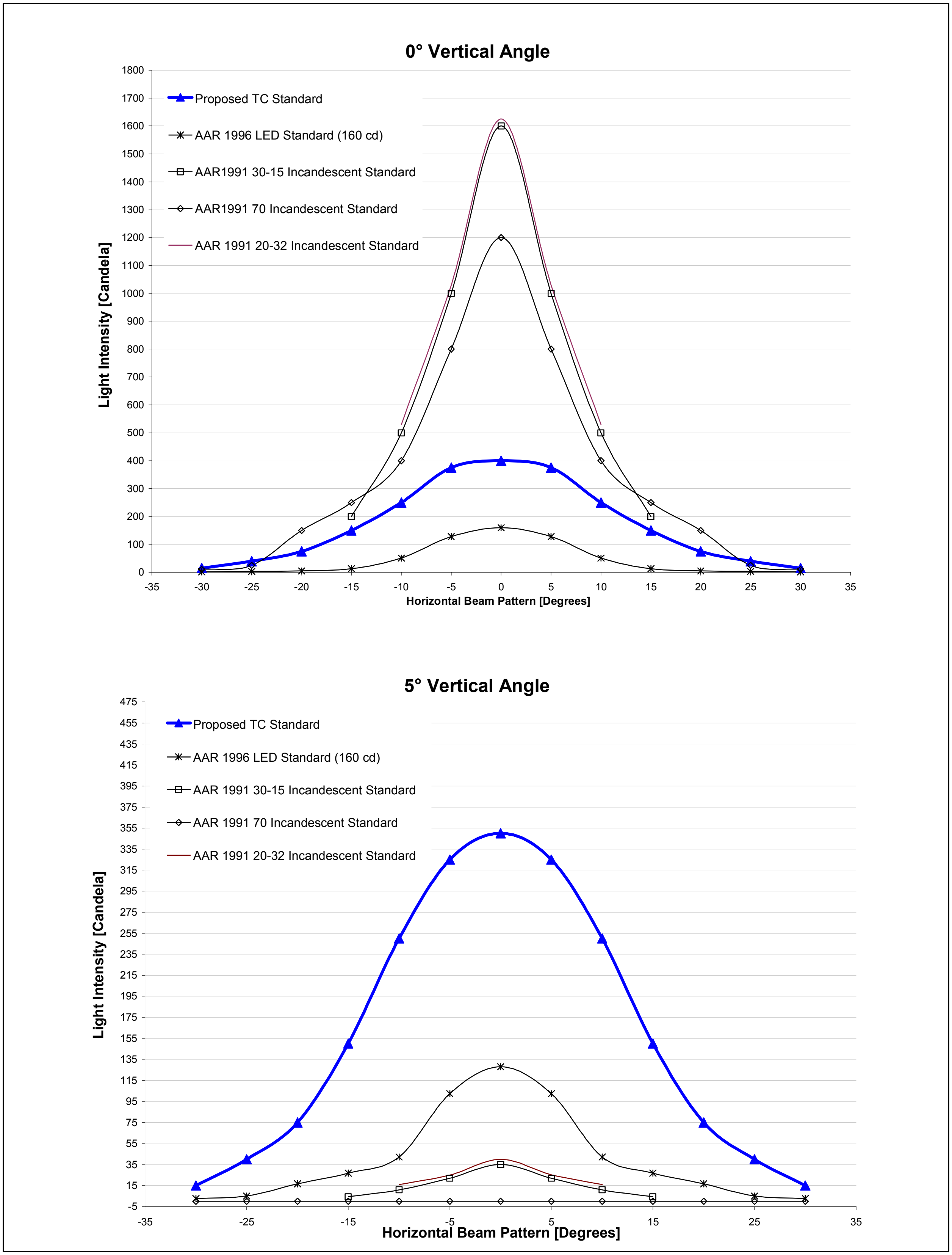
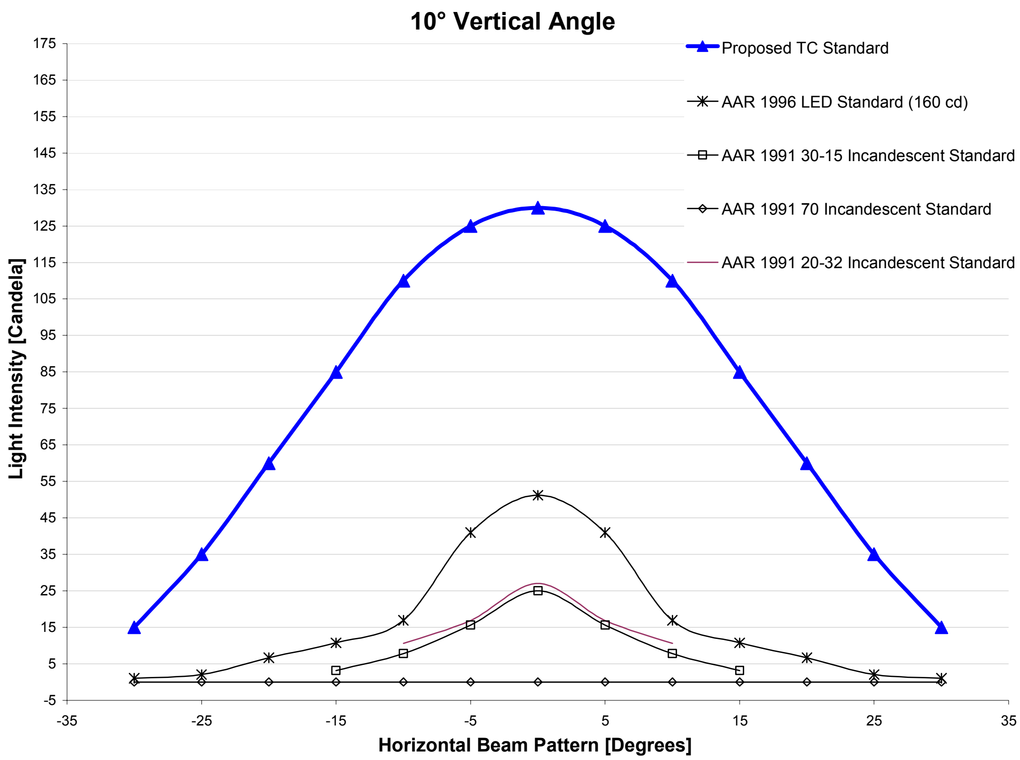


Figure 42 Comparison Between Proposed Photometric Requirements and Previous Railway Photometric Standards



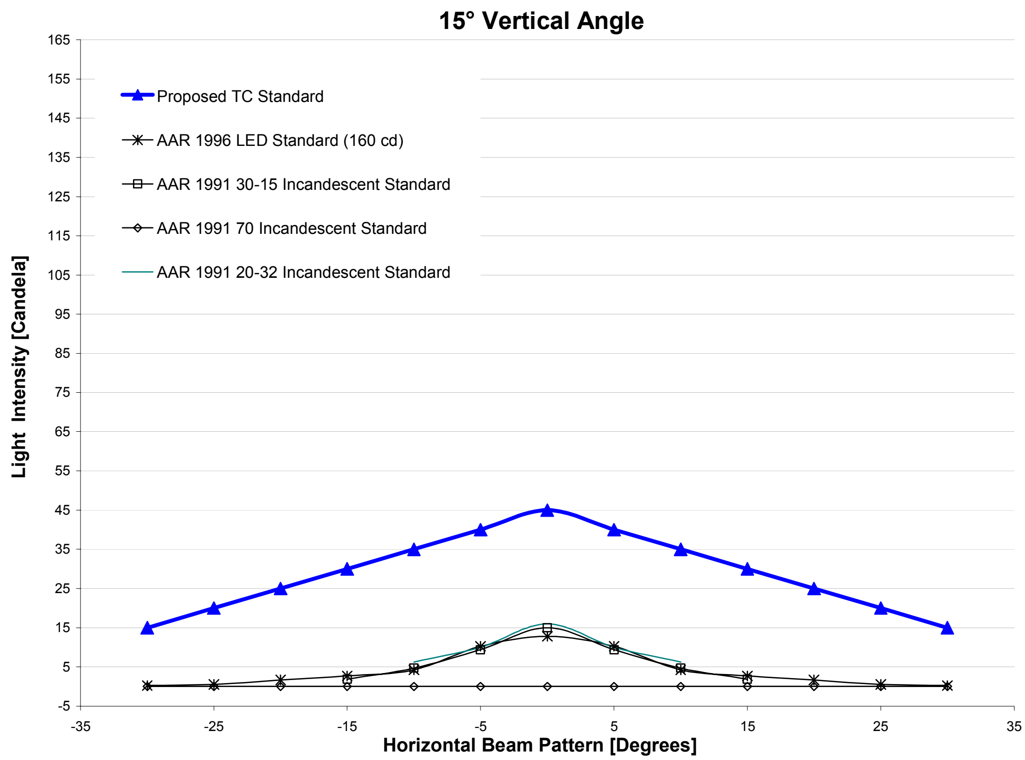


Figure 42 Comparison Between Proposed Photometric Requirements and Previous Railway Photometric Standards (cont.)

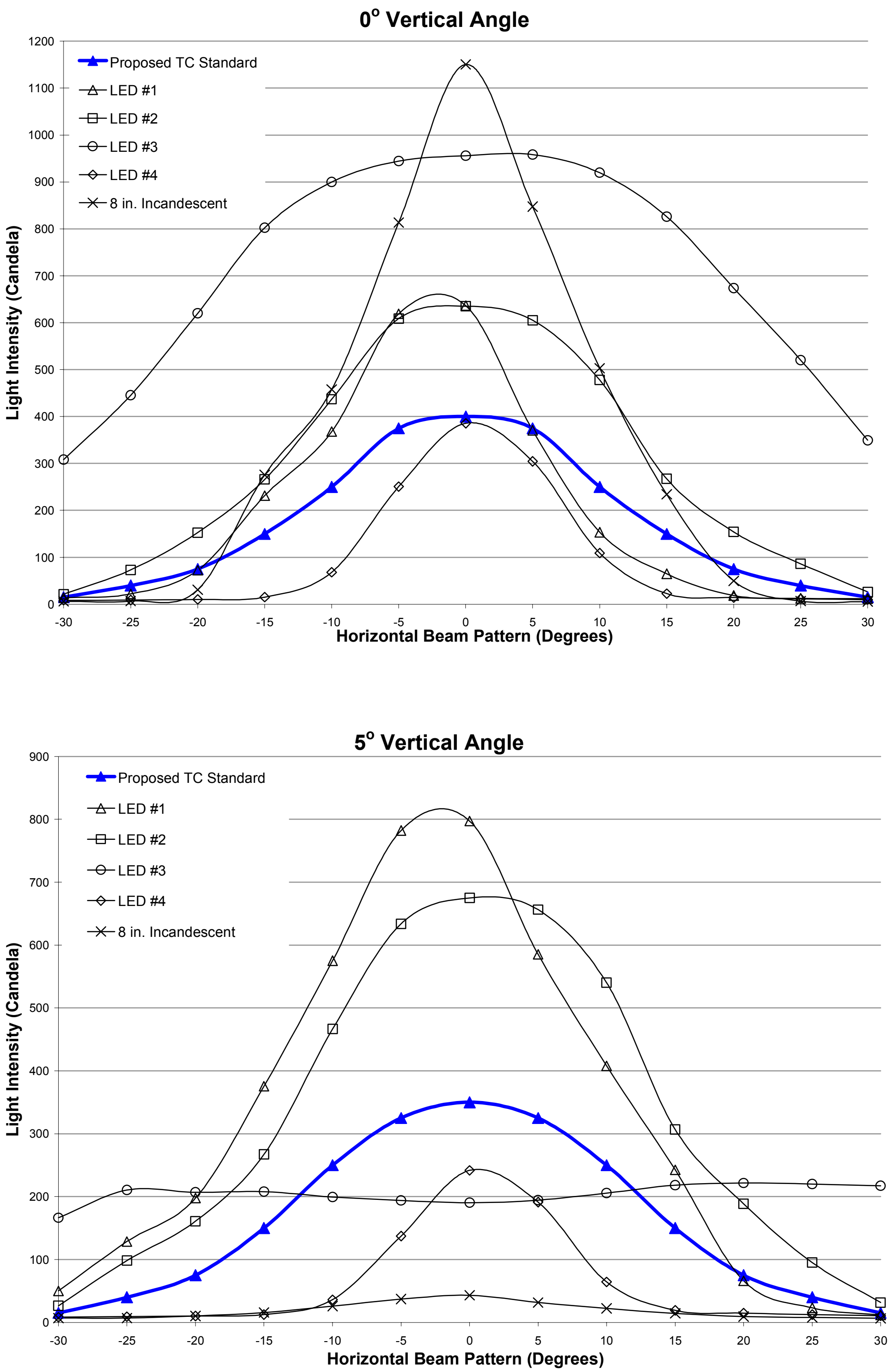


Figure 43 Comparison Between Proposed Photometric Requirements and Sample LED Signal Modules

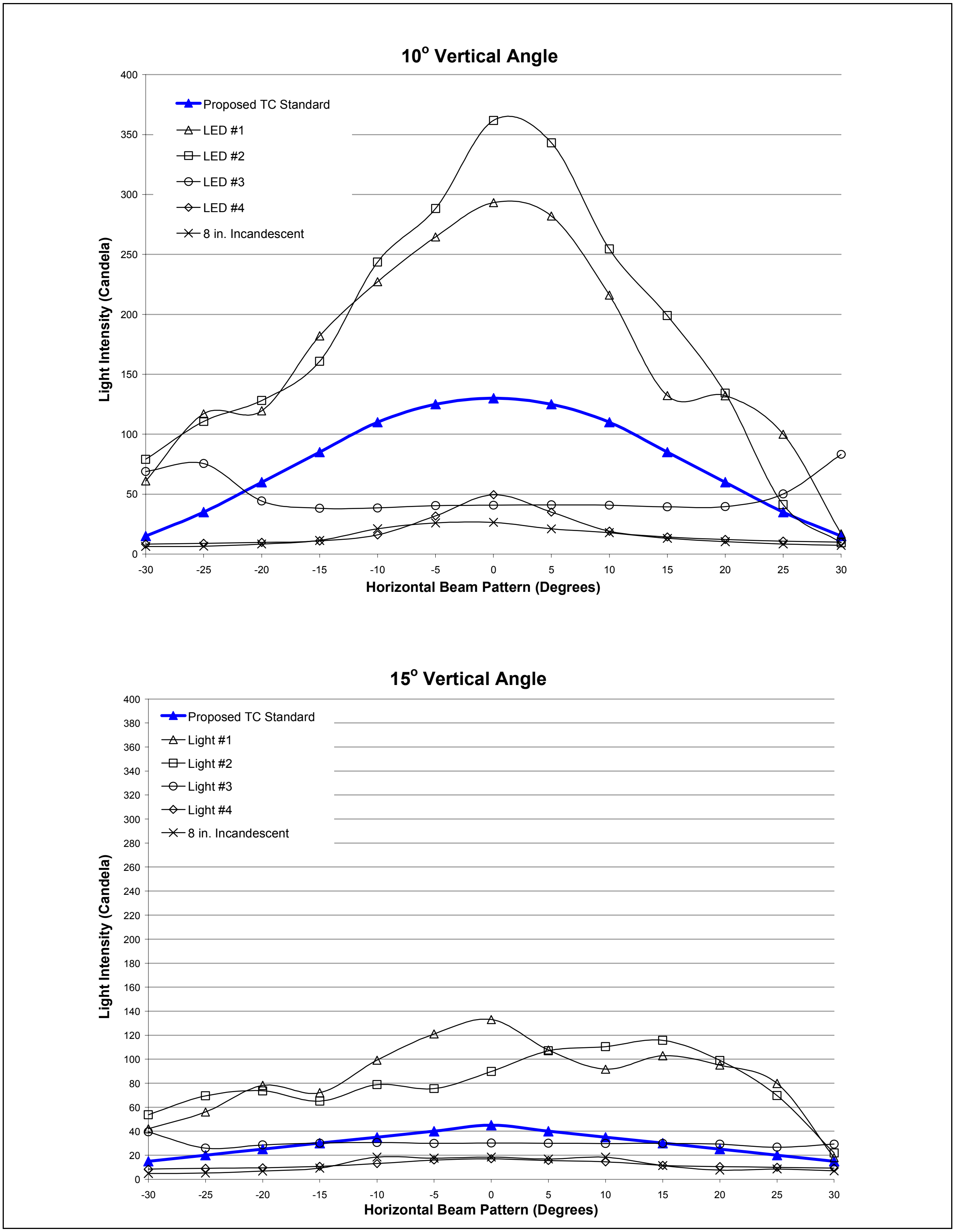


Figure 43 Comparison Between Proposed Photometric Requirements and Sample LED Signal Modules (cont.)

Table 26 – Recommended Chromaticity Regions for Different Standards

Standard	Chromaticity Region
AREMA (Manual Part 7.1.10, 1998)	y < 0.330 y > 0.998-x
ITE (Chapter 2, Section 8.04, 1998)	y < 0.308 y > 0.998-x
CIE (Pub. No. CIE 79, 1988)	y < 0.320 y > 0.990-x y > 0.290

9.13 Requirement for Uniformity

LED signal modules, as we have seen, can be built with many or a few LEDs. There is the potential with LED technology that signal modules could be designed in which the photometric requirements are met by a small number of LEDs creating a small bright spot in the centre of the lens. In order to ensure that the LED signal module is evenly illuminated, we require that the ratio of the greatest and least luminances on the signal module not exceed 5:1 when measured over average areas of 500 mm^2. This requirement is as per CIE *Guide for the Design of Road Traffic Lights*, 1988:

> "It is important that the roundel or symbol of a traffic light should display a fairly uniform luminance over its entire surface, and should have no abrupt changes of luminance. As a result of laboratory experiments, it is proposed that the ratio of the greatest and the least luminances on a roundel should not exceed 10:1, and it is suggested that this ratio should be limited to 5:1. If a traffic light should be constructed of discrete luminous areas, for example, by means of bundles of optical fibres, then it may be desirable for national standards and codes of practice to limit the permissible ratio of the luminances of adjacent areas to less than 5:1."

This standard is more demanding than the European standard (EN12368:2000), which uses a 10:1 ratio. In order to determine whether the CIE standard was too rigorous, we tested five sample LED signal modules. All passed the 5:1 requirement.

TEST PERFORMED	Signal #1	Signal #2	Signal #3	Signal #4	Signal #5
Uniformity of output	3:1	3:1	2:1	2:1	2:1

9.14 Rise Time Requirements

One of the advantages of LEDs is that they can turn on and off instantaneously, which increases their effective intensity when flashing. However, the power supplies for LED signal modules are designed to meet customer requests for constant light output over a wide voltage range on either AC or DC. In meeting these requirements, the power supply itself can result in slow rise and fall times for LED signal modules. As a result, the inherent advantage of LEDs in this regard can be lost. The rise time for incandescent bulbs is approximately 150 ms. We require in the proposed standard that the LED signal module have a faster rise (and fall) time of not more than 75 ms. (The most preferred design would not compromise the instantaneous rise and fall times of the LEDs themselves.)

Imposing a rise and fall time requirement also ensures that, in the future, the flashing rate of railway signals could be increased. The current flashing rate of a maximum of 60 cycles is the maximum that can be achieved with incandescent technology. Reducing the rise and fall time to 75 ms for LED signals would allow the flashing rate to be doubled.

Five different types of sample LED signal modules tested showed widely varying rise and fall times as follows:

TEST PERFORMED	Signal #1	Signal #2	Signal #3	Signal #4	Signal #5
Rise Time	140 ms	139 ms	4 ms	0 ms	36 ms
Fall Time	+300 ms	45 ms	45 ms	0 ms	30 ms

10. ENVIRONMENTAL REQUIREMENTS

10.1 Temperature

The temperature requirements for LED signals are more important than with the older incandescent technology because:

- LED light output varies significantly with temperature, with the light output declining as temperature increases. The effect can be as great as a 1% change for every degree Celcius change in temperature.
- LED signal modules have fairly complex power supplies, whereas incandescent bulbs do not have a power supply at all. The power supplies can introduce important variables in performance, such as not turning on at low temperature.

Figure 44 shows the variation in light output from four sample LED modules as the temperature is increased from room temperature to about 75°C. Not only do the signals decrease in light output, but the effect is not the same for the various modules. By way of contrast, the light output of incandescent signals is not affected by temperature. It is therefore important to require that the LED signal modules meet the required light output over the full range of their operational temperatures. For railway applications, the range of temperatures that has been specified for crossing signals is -40°C to 70°C, so this temperature range has been kept in the proposed standard.

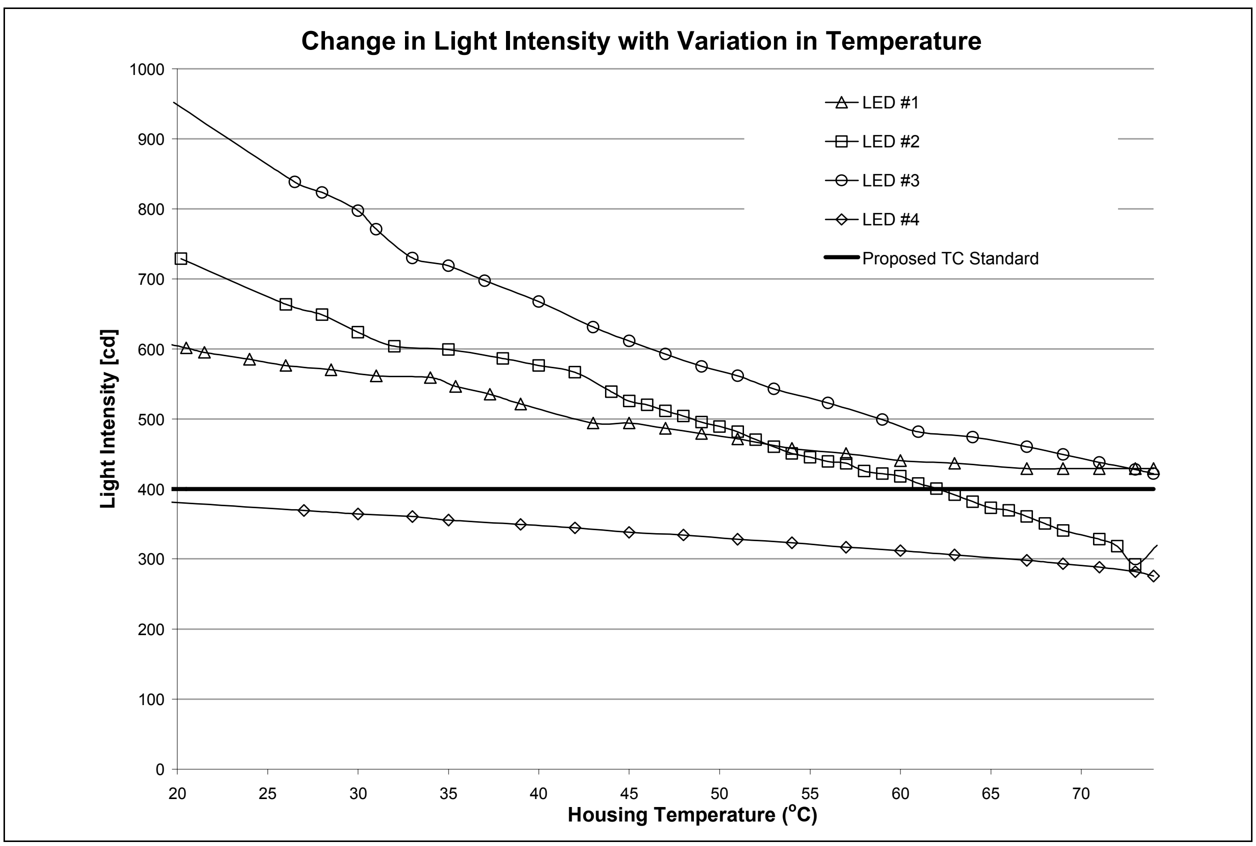


Figure 44 Change in Light Intensity with Temperature Increase, Compared to the Proposed Standard

At very cold temperatures, LEDs produce light efficiently, and light output is not a concern. However, the power supplies for the LEDs can behave erratically at low temperatures. Most commonly, cold temperatures increase the voltage required to turn on an LED signal. (There is no corresponding effect on incandescent signals.) The following table summarizes the voltage required to turn on five different LED signal modules at -40°C. Of the units tested, all turned on at significantly higher voltage at lower temperature. One signal module, signal #3, required over 10 V to turn on properly at -40°C.

TEST PERFORMED	Signal #1	Signal #2	Signal #3	Signal #4	Signal #5
Cold Temperature Operation (-40°C)	On @ 7.9 V	On @ 8.15 V	Barely on at 7 V, dim at 8 V, bottom half goes bright at 9 V (top still dim), same at 10 V.	On @ 7 V	On @ 8 V

In order to ensure that LED signal modules work effectively over the full range of temperature requirements, we state in the purchase specification, and recommend that AREMA 3.2.35 include, that the manufacturer demonstrate effective operation over the full temperature range of -40°C to 70°C, and that the manufacturer supply a graph showing light output over the temperature range of -40°C to 70°C at the nominal operating voltage.

10.2 Continuous Operation

Continuous operation is a second issue that does not occur with incandescent signals, but does with LEDs. If LEDs are left turned on, they gradually heat up, and the temperature effect discussed above causes their light output to decrease. Figure 45 shows the change in light output for four sample LED modules from different manufacturers that are left turned on for 30 minutes. The incandescent signal does not change at all in its light output, but some LED signal modules decline rapidly in their light output before stabilizing. (The difference in the performance of the LED modules over time is not so much due to differences in the LEDs themselves, but rather in the power supplies. Some manufacturers include a temperature compensation circuit in their power supply.)

In order to deal with varying performance over time, we have introduced language into the specification that requires that the LED signal modules meet the photometric standard after one hour of continuous operation. After one hour, the temperature of the LEDs, and their light output, stabilizes, so this provides a stable measurement point.

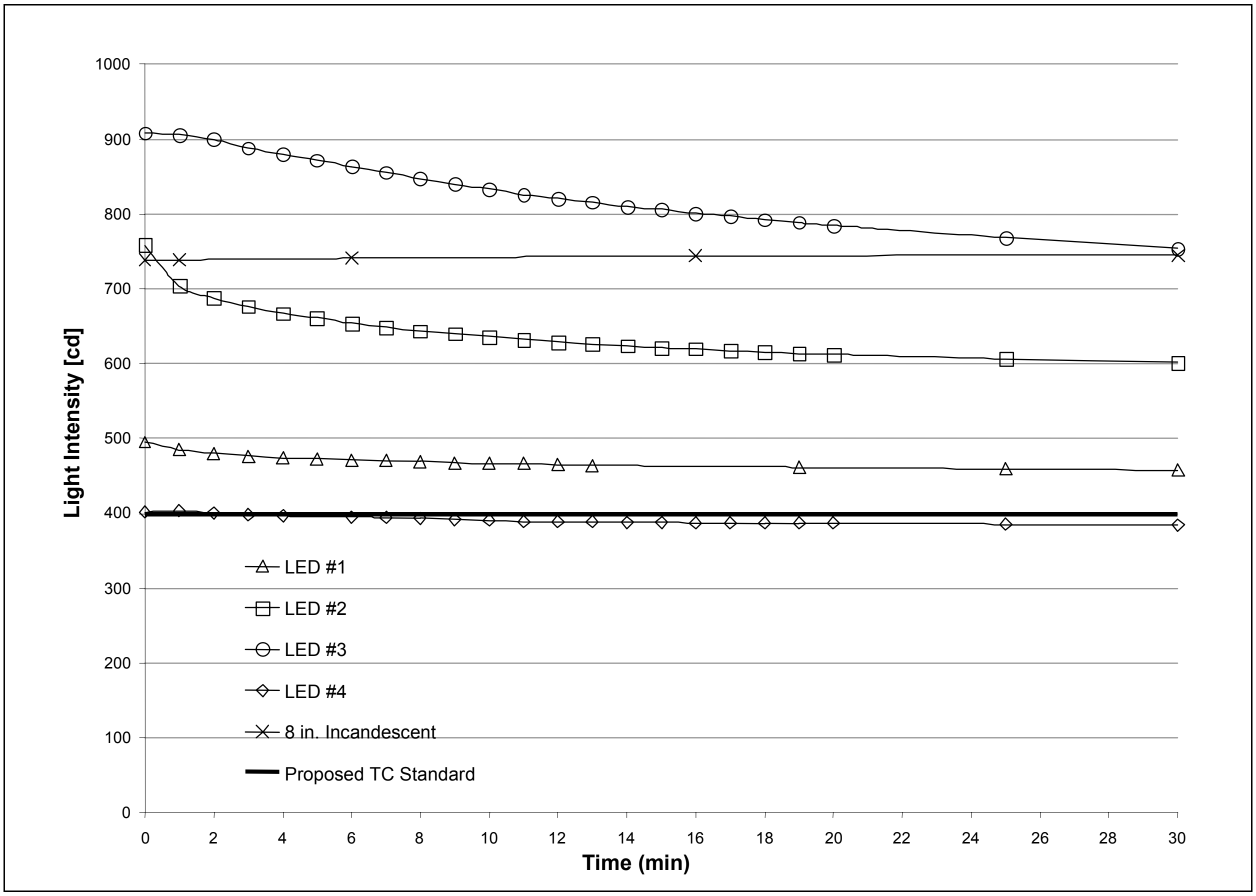


Figure 45 Change in Light Intensity with Time, Compared to the Proposed Standard

10.3 Aging

Both LED and incandescent signals suffer from reduced light output with age. In incandescent signals, bulbs blacken with age. For LEDs, the light output decreases very slowly, but since LEDs last so long, and are left in service so long, the long-term degradation must be addressed.

Compared with red traffic lights, which have about a 40% duty cycle, the average railway crossing signal operation per year is estimated at 300 hours, or about a 3.4% duty cycle. This low duty cycle means that the aging of the LEDs takes a very long time. However, to ensure that the effect is taken into account, we require that the LED signal must still meet the required photometric standard at the end of its projected life, which is estimated at 10,000 hours of operation (33 years at 300 hours per year!). The manufacturer must show that it has allowed a suitable factor for this degradation in comparing the light output of a signal module to the photometric standard.

An aging test of four LED signals, in which the total ‘on-time’ was 1250 hours, did not show a statistically significant decrease in output. According to manufacturers’ data, LEDs can be expected to decrease in light output by about 10% over 10,000 hours of use, although the amount of decrease depends on the current used to drive the LEDs.

The performance of an aged LED signal can be checked in the field against its original performance level using a device such as the Traffic Signal Light Tester Model TSL 2000 by Spectra Light Laboratories (www.spectralightlab.com).

11. PHYSICAL AND MECHANICAL REQUIREMENTS

11.1 Module Design

This standard is for the LED signal module, not the housing itself. The signal module should fit in the existing housings (for example Western Colleen Hayes, Safetran, GRS, Harmon). Manufacturers should specify which housings the modules are compatible with as described in AREMA Communications & Signals Manual Part 3.2.35,1999. The following table shows the result of checking the compatibility of five LED signal modules with various standard housings.

TEST PEFORMED	Signal #1	Signal #2	Signal #3	Signal #4	Signal #5
Housing Compatibility	Yes	Yes	Except one	Yes	Yes

Lens

With LEDs, there is no need for a coloured lens, and indeed a coloured lens may cause a 'phantom effect' when the sun is low, and will absorb a portion of the light output. We recommend that LED signals have clear lenses, but since the public is familiar with red lenses, we recommend allowing red lenses as well. Therefore the housing specification is as per AREMA Communications & Signals Manual Part 3.2.35,1999, except the lens may be either clear or red.

Size

300 mm signals are preferred for high-speed or dangerous roads. 200 mm signals are acceptable where they are deemed to be effective. The standard is intended to apply to both sizes of signals.

Sidelight

The sidelight provides the train with a means of verifying that signals are working. For incandescent signals, bulbs burn out frequently and sidelights simply require a hole in the side of the housing. A sidelight requirement makes sense for incandescent signals. However, with LED signals, the likelihood of failure of the signal is vastly reduced, and the complexity of producing an effective sidelight adds cost and failure mechanisms to the signal. Accordingly, we do not require sidelights in the standard, and sidelights are optional in the purchase specification. Of five sample LED signals tested, only two had effective sidelights.

TEST PERFORMED	Signal #1	Signal #2	Signal #3	Signal #4	Signal #5
Sidelight Functionality	No	Yes	No	No	Yes

Background and Hood

At present the backgrounds and hoods of railway crossing signals are black. With LED lights, the black colour is not ideal, since it absorbs heat and makes the housing hot. Yellow backgrounds are widely used in traffic signals. We therefore recommend using the guideline for backboards from the Manual of Uniform Traffic Control Devices for Canada (MUTCD, Canada), Section B3.2.3, that states that backboards should be yellow although flat black may be used where it is considered to be more effective.

Module Identification

As per AREMA C&S Manual Part 3.2.35, 1999, except:

The LED signal module shall be clearly identified with the following information:

Highway-railway Grade Crossing: LED, Red
Beam Deflection Classification: Universal
Operating Voltage: ____
Current Consumption at Operating Voltage ________________________________
Meets Transport Canada Specifications: 2002
Serial Number: ____
Date of Manufacture: ____

If the module or its components require orientation, they shall be prominently and permanently marked with an upward-pointing arrow.

11.2 Vibration

As per AREMA C&S Manual Part 11.5.1, 1997 (*Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment*).

12. ELECTRICAL REQUIREMENTS

The electrical requirements of the standard refer to AREMA specifications. For example, AREMA 3.2.35 requires that the signal modules be able to work on direct current (10 V nominal); on reverse polarity of direct current, and on 10 V alternating current. This is not a difficult requirement for an incandescent light bulb, since the only component is the resistive wire in the bulb, and it can easily operate under these three conditions. However, for LED operation, these same requirements are not so easily met. LEDs cannot operate under reverse polarity, so a fairly complex power supply is required. Of five sample LED modules tested, four passed this requirement, whereas the fifth did not work on reverse polarity, and flickered on AC operation.

TEST PERFORMED	Signal #1	Signal #2	Signal #3	Signal #4	Signal #4
Reverse Polarity	Yes	Yes	No	Yes	Yes
AC Operation	Yes	Yes	Flicker	Yes	Yes

It may be that AC and reverse polarity requirements will eventually be dropped by AREMA 3.2.35, since they add to the cost and complexity of the signal modules. If a change is made, it will not affect the standard directly, since the standard refers to AREMA requirements on this matter.

In addition to the existing AREMA electrical requirements, there are some new electrical requirements specific to LEDs that we recommend including in AREMA 3.2.35. Testing of sample LED signal modules has shown us that the power supplies used by the various manufacturers introduce anomalies that need to be considered in making purchase decisions.

12.1 Luminous Intensity versus Voltage

With regard to luminous intensity vs. applied voltage, the incandescent bulb behaves in an easily understood manner: as more voltage is applied the signal gets brighter in a reasonably linear manner. However, LED signal modules do not necessarily behave in the manner at all. Figure 46 shows the very different curves of various LED signals, and an incandescent signal.

Our recommendation in the purchase specification, and our recommendation for inclusion in the AREMA speciation, is the following wording:

- The LED signal module shall operate within specification over all voltages likely to be experienced during the normal operation of a signal crossing. Specifically, for existing signal crossing infrastructure, it shall operate within specification when it is powered by either an AC or a DC source over a voltage range of 8.5 to 14 V.
- The manufacturer shall supply a graph of luminous intensity versus voltage over the range of voltages from 0 to 18 V.

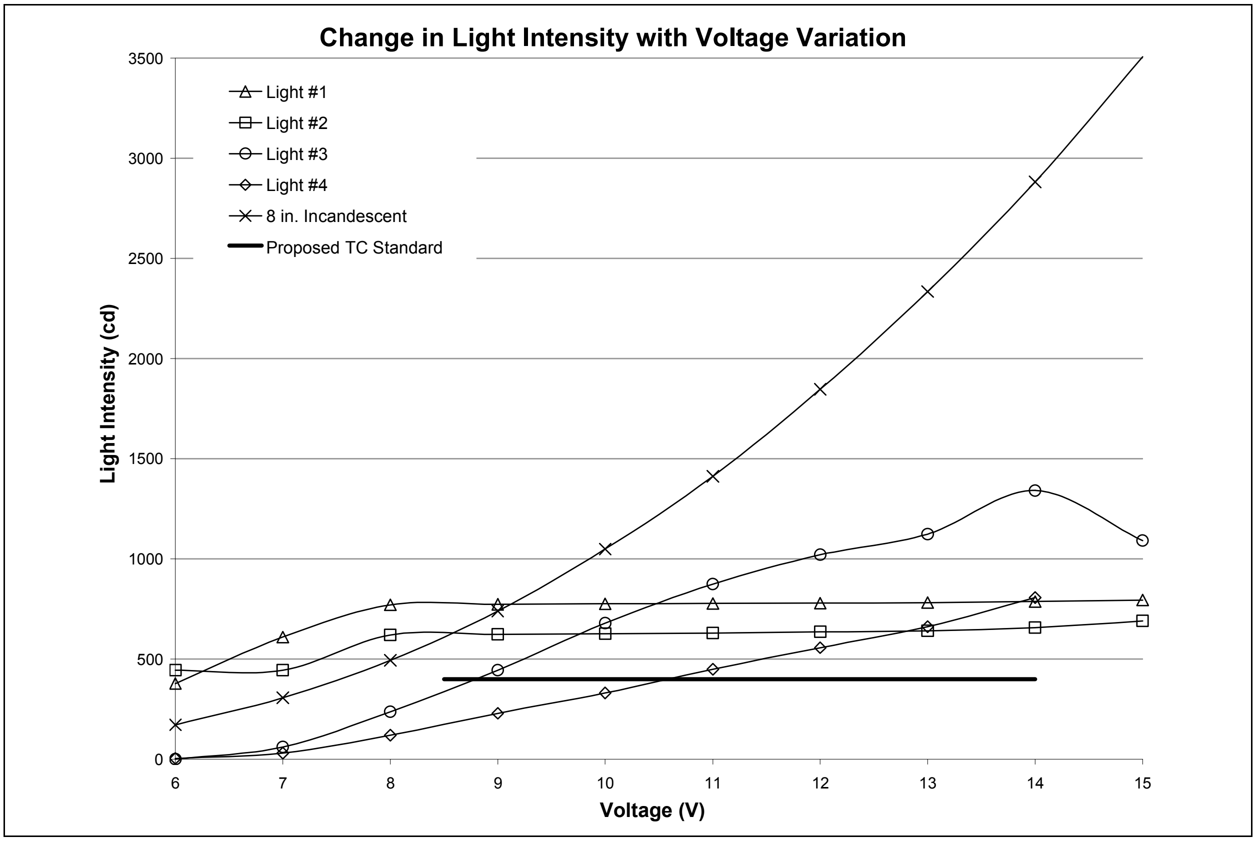


Figure 46 Change in Light Intensity with Voltage, Compared to the Proposed Standard

12.2 Over-Voltage

The existing AREMA specification is not very rigorous with regard to varying applied voltage, calling only for the signal module to work over +/- 15% of the nominal operating voltage. Since the applied voltage can vary considerably more than this, we tested five signal modules up to 20 V applied voltage (DC). Four survived this voltage range, and one blew a component at about 18 V.

- The LED signal module shall be designed so as not to be damaged by moderate over-voltage. Specifically, for current signal crossing infrastructure, it shall not fail when it is powered by either an AC or a DC source of up to 18 V.

TEST PERFORMED	Signal #1	Signal #2	Signal #3	Signal #4	Signal #5
Operational to 20 V applied voltage?	Yes	Yes	No	Yes	Yes

12.3 Current Consumption

Incandescent bulbs used in railway crossing signals are typically 18 W at 10 V, and therefore consume 1.8 A at the nominal operating voltage. In order not to reduce battery operating time in the event of a power failure, and to ensure that the current circuit arrangements at crossings are not compromised, LED signals need to be of about the wattage. Figure 47 shows the results of testing four sample LED signal modules, and an incandescent signal, for their current consumption over the operational voltage range. One LED signal module consumed more and more current as the voltage was reduced, another consumed less, and a third consumed a relatively consistent amount of current over voltage. To ensure that the current consumption of an LED signal module is not excessive, we include the following requirements in our purchase specification, and suggest that AREMA 3.2.35 be adapted to include the same requirements:

- The LED signal module shall consume not more than 2 A over the voltage range likely to be experienced during the normal operation of a signal crossing. The manufacturer shall provide a graph of current consumption versus voltage over the range of 0 to 18 V.

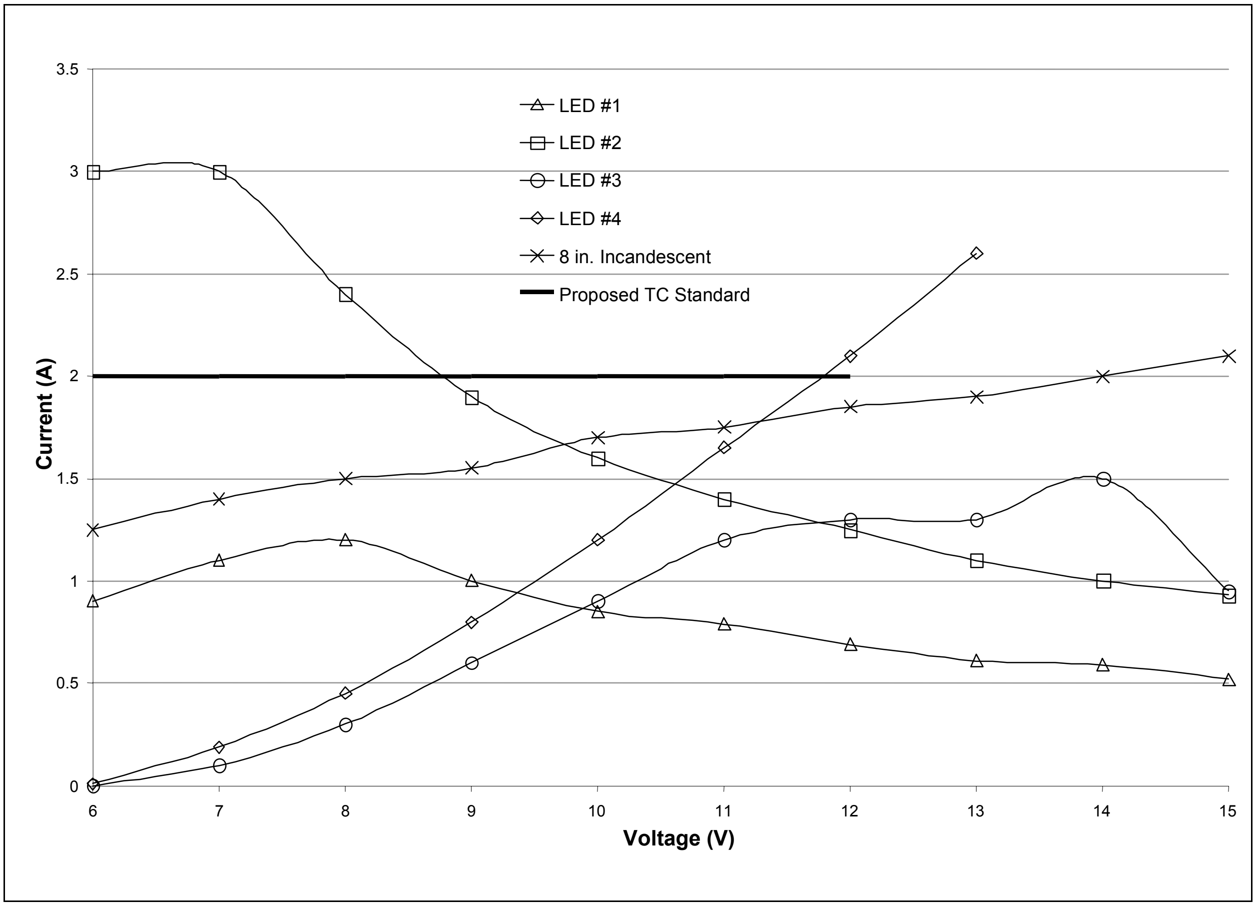


Figure 47 Current Consumption vs. Recommended 2 Amp Maximum Current Draw

12.4 Failure of an LED

One of the advantages of LED technology is that it employs multiple light sources, instead of a single filament as is used in incandescent signals. However, this advantage can be lost if the LED light sources are wired in a way that the failure of one LED causes most of the other LEDs to fail. In order to ensure that the light output can survive the loss of an LED, we recommend the following requirement in the purchase specification:

- The individual LED light sources shall be wired so that a catastrophic failure of one LED light source will result in the loss of not more than 20% of the signal module light output.

We also recommend that AREMA 3.2.35 delete the following wording: "In the case where LEDs are used as a light source, the light unit shall be considered defective when more than 50% of the light-generating diodes are no longer functioning." It is the intention of this standard that the requirement for the luminous intensity must be met at all times. If an LED failure results in a signal module not meeting the standard, then it must be taken out of service.

12.5 In-Rush Current

The power supply circuitry of an LED signal module can result in fairly high in-rush currents being required to turn on the signal. The combination of high in-rush currents from multiple LED signal modules could overload the power supply capabilities at a crossing. The results of testing four different LED signal modules are shown in Figure 48. Three of the four LED signal modules have no significant in-rush current requirements. However, signal #1 requires nearly twice its operating current to turn on, and in addition the power supply is very noisy. In order to ensure that the in-rush requirements are reasonable, the following wording is included in the purchase specification, and is recommended for inclusion in AREMA 3.2.35.

- The in-rush (turn on) current shall be measured and specified as a percentage of operating current.

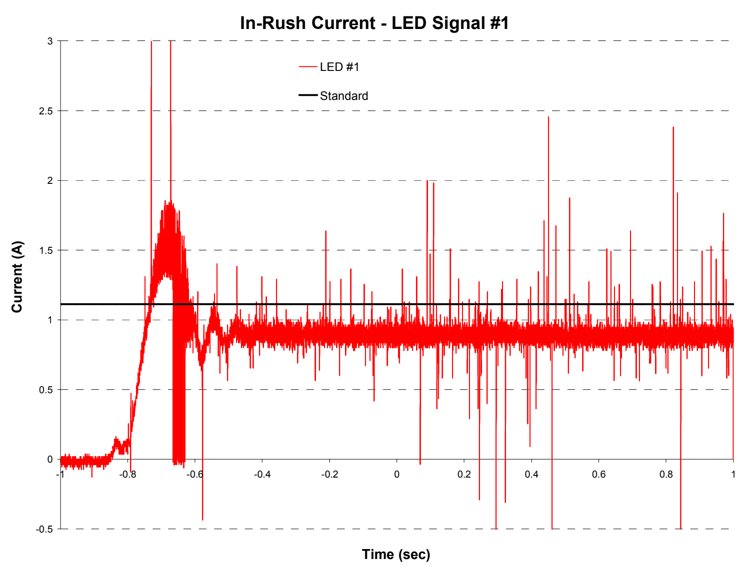


Figure 48 In-Rush Current for Sample LED Signal Modules

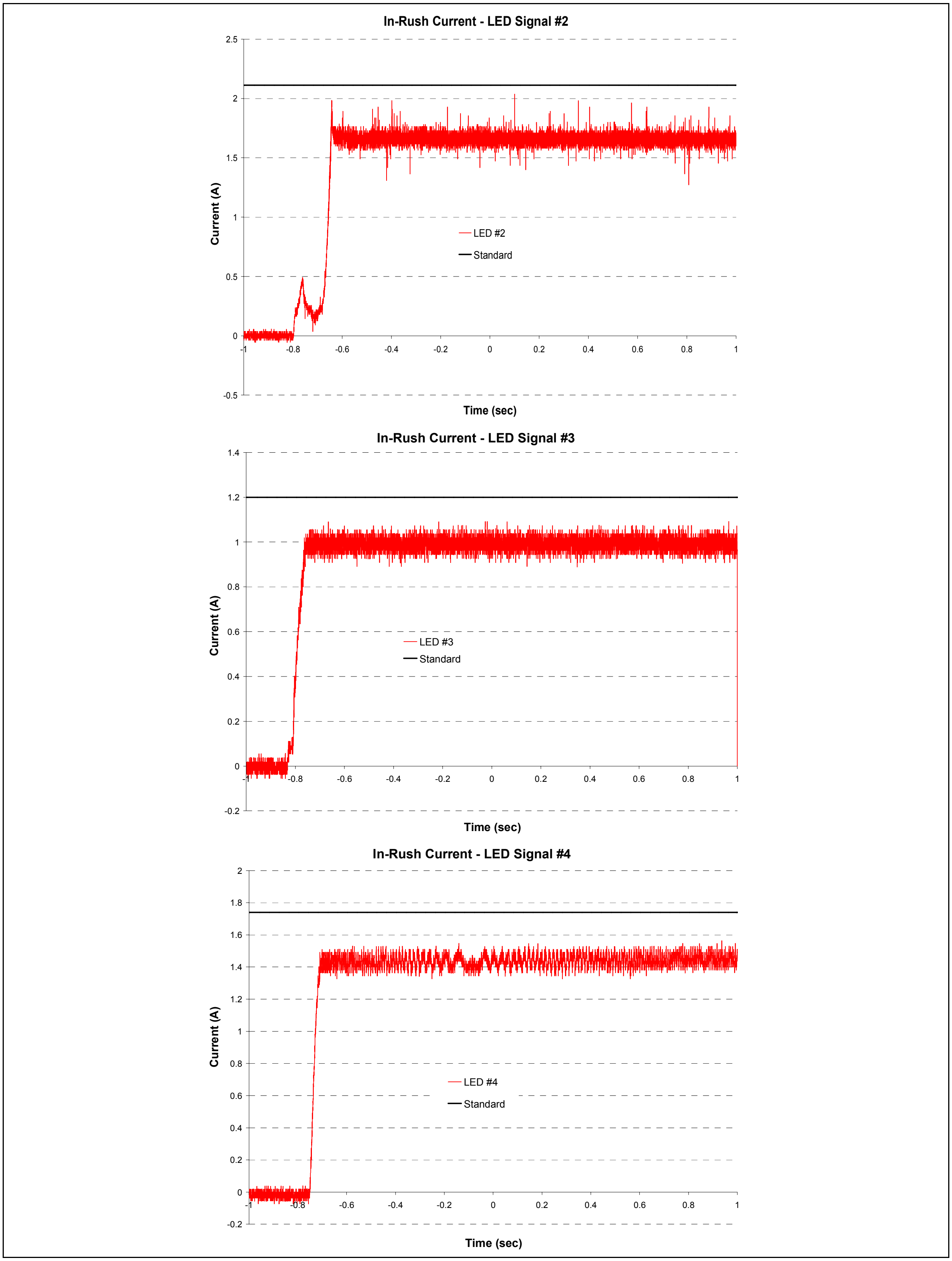


Figure 48 In-Rush Current for Sample LED Signal Modules (cont.)

13. QUALITY ASSURANCE REQUIREMENTS

The quality assurance procedures are essential to ensuring that the requirements of the standard are met, and can be proven to have been met. The ITE specification for LED modules (ITE, 1998) puts considerable effort into designing a good QA system. However, it is not always directly applicable to the low voltage operation of railway signal modules. The recommended QA procedures in our purchase specification for LED crossing modules are modified from the ITE requirements as follows.

13.1 Design Qualification Testing

Maintained Minimum Luminous Intensity

We have tried to state more clearly the voltage, temperature, continuous operation and aging corrections that should be applied to calculate the 'maintained' luminous intensity of a signal module. The temperature testing is as per ITE except somewhat simplified, and the light measurement is on-axis.

13.1.1 Environmental

Temperature Cycling

The temperature test method is as per ITE, but the temperature range is reduced slightly to -40°C to 70°C to conform to the normal AREMA temperature range requirements.

13.1.2 Electrical

Current

This specification is as per ITE, except the current is limited to 2 A at 8.5 to 14 V. We have imposed a maximum current draw of 2 A on the signal modules because of the requirement that railway signal modules be able to run from batteries for extended periods. ITE does not have this consideration. 2 A maximum was chosen to ensure that the signal module does not consume more than 20 W at 10 V, which is approximately the power consumption of the incandescent bulbs commonly used in railway signals.

In-Rush Current

This is specified as 120% of normal current draw. It is included because the complex nature of the power supplies for the railway crossing signal modules can lead to excessive in-rush current.

Dielectric

This specification is taken from AREMA Manual Part 11.5.1 for Class B devices, because there is no requirement in ITE. This is an important consideration in railway applications because the railway tracks are conduits for lightning strikes.

Transient Immunity

This specification is taken from AREMA Manual Part 11.3.3 rather than ITE because the AREMA standard is more stringent.

13.2 Production Quality Assurance Testing

13.2.1 Burn in

As per ITE, except flashing at 60 pulses/min.

14. CONCLUSION

The project has reviewed the standards, both for railway crossings and for highways, human factors, driver requirements, scientific literature and stakeholder comments, and has produced a recommended photometric standard for railway crossing signal lights, and recommended specifications for environmental, electrical, physical and mechanical performance.

The most important part of this requirement, and the least likely to change, is the photometric requirement. The photometric requirement has been codified as a standard, which is intended to be included in Transport Canada's RTD 10, Road/Railway Grade Crossings, Technical Standards and Inspection, Testing and Maintenance Requirements. Once published in RTD-10, the standard will not be easy to modify or update, which is the intended result, since the photometric requirements are intended to remain consistent for many years.

Since it will be difficult to change the RTD 10 standard, requirements that may change with evolving technology refer to AREMA manuals, so the changes can be made in the manuals rather than the standard. One of the AREMA manuals, Manual Part 3.2.35 requires some updating to accommodate the requirements suggested here, while the remainder do not. The key aspects that need to be updated in AREMA 3.2.35 are the photometric requirements, which will need to refer to or agree with the RTD 10 standard, and the electrical requirements. The detailed changes required are listed as recommendations in Section 3.

In the event that the AREMA manual part 3.2.35 is not updated, and to provide further guidance to purchasers, we also provide a purchase specification in Appendix B that includes detailed electrical, physical, mechanical, environmental, and quality assurance requirements for LED signal modules.

15. RECOMMENDATIONS

The standard for LED signal lights refers to manuals produced by the American Railway Engineering and Maintenance-of-Way Association (AREMA) to provide the detailed requirements for mechanical vibration and shock, voltage surge protection, and dielectric and electromagnetic interference. The standard also refers to AREMA Manual 3.2.35 to describe the detailed requirements for LED drive circuitry. However, there are elements of Manual 3.2.35 that need to be updated to conform to the recommendations resulting from this study. Specifically:

1. The standard requires that the luminous intensity be met at all times. If an LED failure results in a signal module not meeting the standard, then it must be taken out of service. Therefore the following wording should be deleted from the Manual:

   In the case where LEDs are used as a light source, the light unit shall be considered defective when more than 50% of the light-generating diodes are no longer functioning.

2. The Manual should include a specific operating voltage requirement that covers all of the normal operating conditions, such as:

   The LED signal module shall operate within specification over all voltages likely to be experienced during the normal operation of a signal crossing. Specifically, for existing signal crossing infrastructure, it shall operate within specification when it is powered by either an AC or a DC source over a voltage range of 8.5 to14 V.

   The manufacturer shall supply a graph of luminous intensity versus voltage over the range of voltages from 0 to 18 V.

3. The Manual calls for the signal module to work over +/- 15% of the nominal operating voltage. Since the applied voltage can vary considerably more than this, we recommend changing this wording to:

   The LED signal module shall be designed so as not to be damaged by moderate over-voltage. Specifically, for existing signal crossing infrastructure, it shall not fail when it is powered by either an AC or a DC source of up to 18 V.

4. To ensure that the current consumption of an LED signal module is not excessive, we suggest the following requirement:

   The LED signal module shall consume not more than 2 A over the voltage range likely to be experienced during the normal operation of a signal crossing. The manufacturer shall provide a graph of current consumption versus voltage over the range of 0 to 18 V.

5. In order to ensure that the in-rush currents necessary to turn on LED lights do not exceed the maximum current design criteria at crossings, we suggest wording to the effect:

   The in-rush (turn on) current shall be specified as a percentage of operating current.

6. In order to ensure that LED signal modules work effectively over the full range of temperature requirements, we recommend that the Manual include a requirement that the manufacturer demonstrate effective operation over the full temperature range of -40°C to

70°C, and provide a graph showing light output over the temperature range of -40°C to 70°C at the nominal operating voltage.

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APPENDIX A:
FULL TEXT OF THE RECOMMENDED STANDARD

TRANSPORT CANADA STANDARD FOR LED SIGNAL MODULES AT HIGHWAY/RAILWAY GRADE CROSSINGS

PURPOSE

The purpose of this standard is to provide the minimum performance requirements for 200 mm and 300 mm Light Emitting Diode (LED) signal modules for use in highway/railway grade crossing signal assemblies in Canada.

DEFINITIONS

Burn-In Process – The procedure by which a LED signal module is energized at an ambient temperature for a specified time duration to cause any early electronic component mortality failures to occur and to detect any component reliability problems before the product is shipped to the end user for installation.

Candela (cd) – SI unit of luminous intensity. The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 nm and that has a radiant intensity in that direction of 1/683 W per steradian (1 cd = 1 lm/sr).

Chromaticity – The colour of the light emitted by an LED signal module, specified as x-y or x and y chromaticity coordinates on the chromaticity diagram according to the 1931 Commission Inernationale d'Eclairage (CIE) standard observer and coordination system.

Duty Cycle – The amount of time during a given unit of time that an LED signal module is actually energized, expressed as a percentage (i.e., 30 minutes per hour would be a 50% duty cycle).

Illuminance (at a point on a surface) – The luminous flux $d\Phi_v$ incident on an element of the surface containing the point divided by the area dA of that element (footcandle, lux)

LED Light Source – A single light emitting diode (LED) or an array of LEDs.

LED Signal Module – An array of LEDs and a lens that together are capable of providing a circular signal indication. An LED signal module shall be capable of replacing the optical unit of an existing highway/ railway grade crossing signal section.

Light Stabilization Procedure The procedure by which an LED signal module is energized at a given temperature for a specified time duration to cause stabilization in light output.

Long Term Luminous Intensity Degradation – The reduction in luminous intensity that normally occurs when an LED is illuminated over an extended period of time.

Lumen (lm) – SI unit of luminous flux. Luminous flux emitted in unit solid angle [steradian (sr)] by a uniform point source having a luminous intensity of 1 candela (1 lm = 1 cd x 1 sr).

Luminance (in a given direction, at a given point on a real or imaginary surface, L_v) – Quantity defined by the formula

$$L_v \quad \frac{d\Phi_v}{dA \cdot d\Omega \cdot \cos\theta}$$

where $d\Phi_v$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle dΩ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam (footlambert, cd/m^2)

Luminous Efficacy of Radiation (K) – The luminous flux Φ_v divided by the corresponding radiant flux Φ_e ($K = \Phi_v/\Phi_e$).

Luminous Efficacy of a Source – The luminous flux emitted divided by the power consumed by the source.

Luminous Intensity (of a source in a given direction, I_v) – The luminous flux $d\Phi_v$ leaving the source and propagating in the element of solid angle dΩ containing the given direction, divided by the element of solid angle ($I_v = d\Phi_v/d\Omega$ candela)

Luminous Flux (Φ_v) – Quantity derived from radiant flux Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer (lumen)

Lux (lx) – SI unit of illuminance. Illuminance produced on a surface of area 1 square metre by a luminous flux of 1 lumen uniformly distributed over that surface (1 lx = 1 lm/m^2)

Power Consumption – The electrical power in watts consumed by an LED signal module when operated at nominal operating voltage and ambient operating temperature range.

Radiant Flux (Φ_e) – The total power emitted, received, or passing in the form of electromagnetic radiation. It is measured in watts.

Rated Life – The arithmetic average of burning hours for a sample number of signal modules operated at rated voltage and under defined operating conditions.

Rated Voltage – The nominal or design operating voltage of the LED signal module; the voltage at which rated watts, candelas, and life are determined.

Rated Watts – The average initial power (watts) consumed when the lamp is operated at rated voltage.

Highway/Railway Grade Crossing Signal – That part of a Highway/Railway Grade Crossing Warning System used at the crossing to provide visual warning to highway traffic.

Spectral Luminous Efficiency – Ratio of the radiant flux at wavelength λ_m to that at wavelength λ such that both radiations produce equally intense luminous sensations under specified photometric conditions and λ_m is chosen so that the maximum value of this ratio is equal to 1.

PHOTOMETRIC REQUIREMENTS

Luminous Intensity

When LED signal modules are in use at a highway/railway grade crossing, they shall at all times and under all normal operational conditions meet the minimum luminous intensity values shown in Table A-1.

Table A-1 – Minimum Luminous Intensity (Candela) over Temperature and Lifetime

	0°	***5° L/R***	***10° L/R***	***15° L/R***	***20° L/R***	***25° L/R***	***30° L/R***
0°	400	375	250	150	75	40	15
5° D	350	325	250	150	75	40	15
10° D	130	125	110	85	60	35	15
15° D	45	40	35	30	25	20	15
20° D	15	15	15	15	15	15	10

Chromaticity

A signal module shall produce a uniform red light output that conforms to the *Equipment and Material Standards* of the Institute of Transportation Engineers (ITE), Chapter 2, Section 8.04, 1998.

Uniformity

The ratio of the greatest and least luminance on the signal module shall not exceed 5:1, when measured over average areas of 500 mm^2.

Rise/Fall Time

The maximum rise time from zero intensity to full intensity, and the maximum fall time from full intensity to zero intensity, shall be 75 ms.

PHYSICAL AND MECHANICAL REQUIREMENTS

LED Signal Module Design

The LED signal module shall be designed to replace the existing signal module holder, reflector, and lens in highway/railway grade crossing signal housings without requiring modification of the mechanical, structural, or electrical components of those housings, which are described in AREMA C&S Manual Part 3.2.35 (*Recommended Design Criteria for Electric Light Unit for Highway-Rail Grade Crossing Signals Including Light Emitting Arrays and Incandescent Lamps*).

The LED signal module may be either 200 mm or 300 mm in size, and may have either a clear or a red lens.

Any gasket or similar sealing provisions shall be made of a material in accordance with AREMA Manual Part 15.2.10 (*Recommended Functional Guidelines for Gasket Material Suitable for Circuit Controllers, Signal Cases and Other Signal Apparatus Housings*).

Environmental Requirements

The LED signal module shall operate over an ambient temperature range of -40°C (-40°F) to 70°C (158°F) per MIL-STD-883, Test Method 1010.

The LED signal module shall be protected against dust and moisture intrusion as per the requirements of NEMA Standard 250-1991, sections 4.7.2.1 and 4.7.3.2, for Type 4 enclosures.

The LED signal module shall be meet mechanical vibration and shock requirements as per AREMA Manual Part 11.5.1 (*Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment*).

The LED signal module lens shall be UV stabilized.

Identification

The LED signal module shall be clearly identified with the following information:

Highway/Railway Grade Crossing: LED, Red
Beam Deflection Classification: Universal
Operating Voltage: ______________________________
Current Consumption at Operating Voltage: ____________________
Meets Transport Canada Specifications: 2002
Serial Number: ______________________________
Date of Manufacture: ______________________________

If the module or its components require orientation, they shall be prominently and permanently marked with an indexing arrow.

ELECTRICAL REQUIREMENTS

Transient Voltage Protection

LED signal module circuitry shall include voltage surge protection as specified in AREMA Manual Part 11.3.3 (*Recommended Design Criteria for Surge Withstand Capability of Electronic Signal Equipment for Signal Systems*).

LED Drive Circuitry

LED signal module circuitry shall operate in accordance with AREMA C&S Manual, Part 3.2.35 (*Recommended Design Criteria for Electric Light Unit for Highway-Rail Grade Crossing Signals Including Light Emitting Arrays and Incandescent Lamps*).

Dielectric and Electromagnetic Interference

LED signal module circuitry shall conform to dielectric and electromagnetic interference requirements for Class B equipment in AREMA Manual Part 11.5.1 (*Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment*).

QUALITY ASSURANCE REQUIREMENTS

LED signal modules shall be manufactured in accordance with a vendor quality assurance (QA) program. The QA program shall include two types of quality assurance:

- design quality assurance, and
- production quality assurance.

The design quality assurance program will ensure that the luminous intensity requirements of this specification will be met under all normal operational conditions and over the installed life of the product, as well as ensuring that the physical, mechanical and electrical requirements of this specification are met.

The production quality assurance shall include statistically controlled routine tests to ensure that each LED signal module meets the design specifications.

APPENDIX B:
PURCHASE SPECIFICATION

PURCHASE SPECIFICATION FOR LED SIGNAL MODULES AT HIGHWAY/RAILWAY GRADE CROSSINGS

PURPOSE

The purpose of this purchase specification is to provide detailed performance and quality assurance requirements for 200 mm and 300 mm Light Emitting Diode (LED) signal modules for use in highway-railway grade crossing signal assemblies.

This specification is intended to aid purchasers of LED railway signal modules and to impose restrictions upon specific designs and materials that conform to the purpose and the intent of this specification. It applies to LED signal modules purchased after July 2002.

DEFINITIONS

Burn-In Process – The procedure by which a LED signal module is energized at an ambient temperature for a specified time duration to cause any early electronic component mortality failures to occur and to detect any component reliability problems before the product is shipped to the end user for installation.

Candela (cd) – SI unit of luminous intensity. The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 nm and that has a radiant intensity in that direction of 1/683 W per steradian (1 cd = 1 lm/sr).

Chromaticity – The colour of the light emitted by an LED signal module, specified as x-y or x and y chromaticity coordinates on the chromaticity diagram according to the 1931 Commission Inernationale d'Eclairage (CIE) standard observer and coordination system.

Duty Cycle – The amount of time during a given unit of time that an LED signal module is actually energized, expressed as a percentage (i.e., 30 minutes per hour would be a 50% duty cycle).

Illuminance (at a point on a surface) – The luminous flux $d\Phi_v$ incident on an element of the surface containing the point divided by the area dA of that element (footcandle, lux)

LED Light Source – A single light emitting diode (LED) or an array of LEDs.

LED Signal Module – An array of LEDs and a lens that together are capable of providing a circular signal indication. An LED signal module shall be capable of replacing the optical unit of an existing highway/ railway grade crossing signal section.

Light Stabilization Procedure The procedure by which an LED signal module is energized at a given temperature for a specified time duration to cause stabilization in light output.

Long Term Luminous Intensity Degradation – The reduction in luminous intensity that normally occurs when an LED is illuminated over an extended period of time.

Lumen (lm) – SI unit of luminous flux. Luminous flux emitted in unit solid angle [steradian (sr)] by a uniform point source having a luminous intensity of 1 candela (1 lm = 1 cd x 1 sr).

Luminance (in a given direction, at a given point on a real or imaginary surface, L_v) – Quantity defined by the formula

$$L_v \quad \frac{d\Phi_v}{dA \cdot d\Omega \cdot \cos\theta}$$

where $d\Phi_v$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam (footlambert, cd/m^2)

Luminous Efficacy of Radiation (K) – The luminous flux Φ_v divided by the corresponding radiant flux Φ_e ($K = \Phi_v/\Phi_e$).

Luminous Efficacy of a Source – The luminous flux emitted divided by the power consumed by the source.

Luminous Intensity (of a source in a given direction, I_v) – The luminous flux $d\Phi_v$ leaving the source and propagating in the element of solid angle $d\Omega$ containing the given direction, divided by the element of solid angle ($I_v = d\Phi_v/d\Omega$ candela)

Luminous Flux (Φ_v) – Quantity derived from radiant flux Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer (lumen)

Lux (lx) – SI unit of illuminance. Illuminance produced on a surface of area 1 square metre by a luminous flux of 1 lumen uniformly distributed over that surface ($1\ lx = 1\ lm/m^2$)

Power Consumption – The electrical power in watts consumed by an LED signal module when operated at nominal operating voltage and ambient operating temperature range.

Radiant Flux (Φ_e) – The total power emitted, received, or passing in the form of electromagnetic radiation. It is measured in watts.

Rated Life – The arithmetic average of burning hours for a sample number of signal modules operated at rated voltage and under defined operating conditions.

Rated Voltage – The nominal or design operating voltage of the LED signal module; the voltage at which rated watts, candelas, and life are determined.

Rated Watts – The average initial power (watts) consumed when the lamp is operated at rated voltage.

Highway/Railway Grade Crossing Signal – That part of a Highway/Railway Grade Crossing Warning System used at the crossing to provide visual warning to highway traffic.

Spectral Luminous Efficiency – Ratio of the radiant flux at wavelength λ_m to that at wavelength λ such that both radiations produce equally intense luminous sensations under specified photometric conditions and λ_m is chosen so that the maximum value of this ratio is equal to 1.

PHOTOMETRIC REQUIREMENTS

Luminous Intensity

The maintained luminous intensity values for LED railway signal modules throughout 10,000 hours of projected use and under all normal operating conditions (temperature range of -40°C to 70°C and voltage range of 8.5 to 14 V AC/DC), shall not be less than the values shown in Table B-1.

Table B-1 – Minimum Luminous Intensity (Candela) over Temperature and Lifetime

	0°	***5° L/R***	***10° L/R***	***15° L/R***	***20° L/R***	***25° L/R***	***30° L/R***
0°	400	375	250	150	75	40	15
5° D	350	325	250	150	75	40	15
10° D	130	125	110	85	60	35	15
15° D	45	40	35	30	25	20	15
20° D	15	15	15	15	15	15	10

Chromaticity

A signal module shall produce a uniform red light output that conforms to the *Equipment and Material Standards* of the Institute of Transportation Engineers (ITE), Chapter 2, Section 8.04, 1998.

Uniformity

The ratio of the greatest and least luminances on the signal module shall not exceed 5:1, when measured over average areas of 500 mm^2.

Rise Time

The maximum rise time from zero intensity to full intensity, and the maximum fall time from full intensity to zero intensity, shall be 75 ms.

PHYSICAL AND MECHANICAL REQUIREMENTS

LED Signal Module Design

The LED signal module shall be designed to replace the existing signal module holder, reflector, and lens in highway-railway grade crossing signal housings without requiring modification of the mechanical, structural, or electrical components of those housings, which are described in AREMA C&S Manual Part 3.2.35 (*Recommended Design Criteria for Electric Light Unit for Highway-Rail Grade Crossing Signals Including Light Emitting Arrays and Incandescent Lamps*).

The LED signal module may be either 200 mm or 300 mm in size, and may have either a clear or a red lens.

Replaceable component parts of an LED signal module shall be designed to be interchangeable with like parts from the same manufacturer or supplier.

Any gasket or similar sealing provisions shall be made of a material in accordance with AREMA Manual Part 15.2.10 (*Recommended Functional Guidelines for Gasket Material Suitable for Circuit Controllers, Signal Cases and Other Signal Apparatus Housings*).

Optional: Visual indications shall be provided that are visible to train crews as they approach the highway-rail grade crossing to verify that the LED signal modules are operating.

Environmental Requirements

The LED signal module shall operate over an ambient temperature range of -40°C (-40°F) to 70°C (158°F) per MIL-STD-883, Test Method 1010.

The LED signal module shall be protected against dust and moisture intrusion as per the requirements of NEMA Standard 250-1991, sections 4.7.2.1 and 4.7.3.2, for Type 4 enclosures.

The LED signal module shall be meet mechanical vibration and shock requirements as per AREMA Manual Part 11.5.1 (*Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment*).

The LED signal module lens shall be UV stabilized.

Identification

The LED signal module shall be clearly identified with the following information:

Highway/Railway Grade Crossing: LED, Red
Beam Deflection Classification: Universal
Operating Voltage: ____
Current Consumption at Operating Voltage: ___________________________
Meets Transport Canada Specifications: 2002
Serial Number: ____
Date of Manufacture: ____

If the module or its components require orientation, they shall be prominently and permanently marked with an indexing arrow.

ELECTRICAL REQUIREMENTS

Transient Voltage Protection

LED signal module circuitry shall include voltage surge protection as specified in AREMA Manual Part 11.3.3 (*Recommended Design Criteria for Surge Withstand Capability of Electronic Signal Equipment for Signal Systems*).

LED Drive Circuitry

The LED signal module shall operate within specification over all voltages likely to be experienced during the normal operation of a signal crossing. Specifically, for existing signal crossing infrastructure, it shall operate within specification over a voltage range of 8.5 to 14 V. The manufacturer shall provide a graph of on-axis intensity vs. applied voltage over the range of 0 to 18 V.

The LED signal module shall be designed so as to not be damaged by moderate over-voltage. Specifically, for current signal crossing infrastructure, it shall not fail when it is powered by either an AC or a DC source of up to 18 V.

The LED signal module shall not consume more than 2 A over the voltage range likely to be experienced during the normal operation of a signal crossing. The manufacturer shall provide a graph of current consumption vs. voltage over the range of 0 to 18 V.

Polarity in DC powered applications shall be internal to the unit and not require observance of polarity for connection to the existing housing terminals.

Electrical connections shall be insulated stranded copper wires of sufficient size for the maximum operating current of the light source. In no case shall the wiring be less than No. 16 AWG, and shall be terminated with insulated, positive retention connectors compatible with the housing terminals. There shall be no requirement for intermediate connectors or other types of adapters.

The individual LED light sources shall be wired so that a catastrophic failure of one LED light source will result in the loss of not more than 20% of the signal module light output.

Dielectric and Electromagnetic Interference

LED signal module circuitry shall conform to dielectric and electromagnetic interference requirements for Class B equipment in AREMA Manual Part 11.5.1 (*Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment*).

QUALITY ASSURANCE REQUIREMENTS

General

Quality Assurance Program

LED signal modules shall be manufactured in accordance with a vendor quality assurance (QA) program. The QA program shall include two types of quality assurance: (1) design quality assurance, and (2) production quality assurance. The production quality assurance shall include statistically controlled routine tests to ensure minimum performance levels of LED signal modules built to meet this specification.

Record Keeping

QA process and test results documentation shall be kept on file for a minimum period of seven years.

Conformance

LED signal module designs not satisfying design qualification testing and the production quality assurance testing performance requirements shall not be labelled, advertised, or sold as conforming to this specification.

Design Qualification Testing

Burn In

Three LED signal modules shall be flashed for a minimum of 24 hours at 50% duty cycle flash, and at an ambient temperature of 60°C (+140°F), prior to undergoing the following tests.

Luminous Intensity

The three LED signal modules will be tested for their luminous intensity at an ambient temperature of 25°C and at the expected operating voltage after the signal has been operated continuously, without flashing, for one hour. These measurements shall be recorded in a luminous intensity chart at the points indicated in Table B-1.

Effects of Temperature
The three LED modules shall then be tested for their performance over temperature. After one hour of continuous operation at 70°C, the light output shall be measured on-axis. The light output shall then be measured at 10°C degree increments to -40°C. Manufacturers shall supply a graph showing on-axis light output vs temperature over this temperature range, and supply a correction factor that corrects for the 'worst case' effect of temperature.

Effects of Voltage
The luminous intensity of the three LED signal modules will be determined over the voltage range from 0 to 18 V at 25°C. The manufacturer shall supply a graph showing the luminous intensity versus voltage over this voltage range, and shall provide a correction factor that corrects for the worst case of luminous intensity over the voltage range of 8.5 to 14 V DC

(or other such voltage range that reflects the full range of voltages likely to be encountered in field operation).

Effects of Aging
The manufacturer shall provide the current going through the LEDs in the LED signal module, and, based on the LED manufacturers estimates of degradation in luminous intensity over time, shall calculate a correction factor for the effects of 10,000 hours of use at room temperature.

Corrected Version of Luminous Intensity Chart
These three correction factors will be applied to adjust the results of the luminous intensity chart, which will then be compared with Table 1 in the specification. All or substantially all of the corrected measurements must meet the requirements as specified in Table B-1.

Chromaticity

Three LED signal modules shall be measured for chromaticity per the requirements of this standard. The ambient temperature for this measurement shall be 25°C (77°F).

Uniformity

Three LED signal modules shall be tested for uniformity of luminance. The ratio of the greatest and least luminances on the signal module shall not exceed 5:1 when measured over average areas of 500 mm^2 using procedures as specified in CIE *Guide for the Design of Road Traffic Lights*, 1988.

Mechanical Vibration

Three LED signal modules shall be tested for mechanical vibration as per requirements for Wayside Outdoor Equipment (Class B), AREMA Manual Part 11.5.1 (*Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment*). The loosening of the lens or of any internal components or other physical damage shall be cause for rejection.

Environmental

Temperature Cycling
Temperature cycling shall be performed on a sample of three LED signal modules per MIL-STD-883, Test Method 1010. The temperature range shall be between -40°C and 70°C. A minimum of 20 cycles shall be performed with a 30-minute transfer time between temperature extremes and a 30-minute dwell time at each temperature. Signals under test shall be non-operating. Failure of a module to function properly or any evidence of cracking of the module lens or housing after temperature cycling shall be cause for rejection.

Moisture Resistance
Moisture resistance testing shall be performed on three LED signal modules per NEMA Standard 250-1991 for Type 4 enclosures. Any evidence of internal moisture after testing shall be cause for rejection.

Electrical

Current
Three LED signal modules shall be measured for current flow in amperes. The measured current values shall be used for quality comparison of Production Quality Assurance current measurement on production modules. The manufacturer shall provide a graph showing the variation in current consumption versus voltage from 0 V to 18 V at 25°C.The average current shall not exceed 2 A when the applied voltage is 8.5 to 14 V.

In-rush Current
The in-rush (turn on) current shall be measured and specified as a percentage of operating current.

Electric Noise
Three LED signal modules shall be tested per the requirements of Federal Communication Commission, with reference to Class A emission limits referenced in Federal Communication Commission (FCC) Title 47, SubPart B, Section 15.

Dielectric
Three LED signal modules shall be tested to ensure they conform to the dielectric requirements of Class B of AREMA Manual Part 11.5.1 (*Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment, Class B*).

Transient Immunity
Three LED signal modules shall be tested for transient immunity using the procedure described in AREMA Manual Part 11.3.3 (*Recommended Design Criteria for Surge Withstand Capability of Electronic Signal Equipment for Signal Systems*).

Production Quality Assurance Testing

Production runs of LED signal modules shall be statistically sampled according to standard production quality assurance procedures. The sample LED signal modules shall be subjected to the following quality assurance tests.

LED Signal Module Burn In

All sample LED signal modules shall be flashed for a minimum of 24 hours at 50% duty cycle and at an ambient temperature of 60°C (+140°F) prior to undergoing the following tests.

Maintained Minimum Luminous Intensity

All sample LED signal modules shall be tested for their on-axis luminous intensity after one hour of sustained operation (or, alternatively, corrected for the effect of one hour of continuous operation) at 25°C, and at the expected operating voltage. The measured luminous intensity shall be at least 400 cd after allowing for the worst case effects of temperature (-40° to 70°C), voltage (8.5 to 14 V), and 10,000 hours of use by applying the correction factors supplied by the design quality assurance procedures. LED signal modules shall be rejected if they do not meet the required minimum luminous intensity.

Current Draw

All sample LED signal modules shall be measured for their current consumption in Amperes after burn-in. Current consumption greater than 120% of the design current at the expected operating voltage will result in rejection of the signal module.

Visual Inspection

All sample LED signal modules shall be visually inspected for any exterior physical damage or assembly anomalies. Careful attention shall be paid to the surface of the lens to ensure there are no scratches (abrasions), cracks, chips, discoloration, or other defects. Any such defects shall be cause for rejection.

APPENDIX C
STAKEHOLDER LIST

The following is a list of stakeholders who contributed to this project via participation, interview or by providing feedback on the web or directly. A summary of all of stakeholder feedback is available on the web at: www.railwaycrossings.com.

Steering Committee

- Peter Brackett
  Engineer, CPR, Calgary, Alberta

- Gordon Eisenhuth
  Rail, Navigable Waters Coordinator – Highway Engineering Branch,
  Ministry of Transportation, Victoria, British Columbia

- Daniel Lafontaine
  Engineer, Manager Grade Crossing Programs, Transport Canada, Ottawa, Ontario

- Frank Lalonde
  Engineering Manager, Transport Canada – Surface, Montreal, Quebec

- Réal Kirouac
  Engineer, Canadian National, Montreal, Quebec

- Peter Mayer,
  Acting Chief of Signal Systems, Transport Canada, Ottawa, Ontario

- Anthony Napoli
  Transportation Consultant, Transportation Development Centre,
  Transport Canada, Montreal, Quebec

- John Sharkey
  General Manager Marketing, Safetran, Elgin, Illinois, USA

- Sesto Vespa
  Senior Development Officer, Transportation Development Centre,
  Transport Canada, Montreal, Quebec

Manufacturers and Distributors

- Dominic Balthazar,
  Product Manager, GELcore

- Martyn Cook
  Marketing Director, Vega Industries, New Zealand

- Kirk Knight
  Sales & Marketing, General Signals Inc.

- Frank Legge
  Product Manager, Milrail

- Paolo Paoletta
  Market Specialist, GELcore

- Richard Present
  Business Development Manager, Dialight

- Nicolas St-Germain and Claude Boisvert
  Engineering, GELcore

- John Sharkey
  General Manager Marketing, Safetran

- Emmett Smith
  Application Engineer, Agilent

- William Wilson
  Canadian Manager, Safetran

- Lenny Wydotis
  Engineer, Safetran

Railway Industry

- James Cheeks
  ITE Committee

- Rene Lafleche and Ray Kroeker
  Engineers, CN

- Robert W. McKnight
  Railway Signaling Historian

- Bob Nash
  General Manager Signals, CPR

- Stephen Patrick
  Engineer-S&C Development and Quality Assurance, CPR

- Dan Van Alstine
  President, Rail Development Group, LLC, Lima, New York, USA

Government Regulatory Bodies

- Mike Coghlan
  Director Engineering, Rail Safety, Transport Canada

- Gary Drouin
  National Administrator for Direction 2006, Transport Canada

- Ivan Mann
  Railway Safety Manager for Pacific Region, Transport Canada Surface

- Ron Mitchell
  Manager, Railway Safety Engineering, Pacific Region, Transport Canada

- Allan Neilson, Manager
  STE (Signals Telecomms and Electrical) Infrastructure TranzRail Limited, New Zealand

- Sandy Quesnel
  B.C. Ministry of Transportation

- John Riley
  Signal Systems Crossing Officer for Pacific Region, Transport Canada

Legal Profession

- Kenneth A. Stevenson
  Q.C., Priel, Stevenson, Hood & Thornton, Saskatoon, Saskatchewan

Academia

- Matthew Chatham
  University of Alabama, Graduate Student

- Joey Parker
  University of Alabama, Associate Professor