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October 15, 2007

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby BC V5A 1S6

Re: ENSC 440 Functional Specification for the Smart Traffic Light

Dear Dr. Rawicz,

The attached document contains the functional specification for the Smart Traffic Light. We are designing a traffic light that is sensitive to vision limiting weather conditions such as fog and can significantly reduce automobile accidents that are caused by misinterpretation of traffic lights due to sun glare.

The functional specification details the requirements of the Smart Traffic Light. Due to well established standards for traffic lights in North America, particular emphasis is placed on the requirements of the new features of our device.

AnoLED Technology Inc. is comprised of four senior-level engineering students, namely, Jamal Bahari, Ighodalo Iyayi, Behrad Kajbafzadeh, and Sara Rokni. Should you have any questions, feel free to contact me at 250.552.4140 or, alternatively, by email at 440-ensc-project@sfu.ca.

Sincerely,

Ighodalo Iyayi
Chief Executive Officer (CEO)
AnoLED Technology Inc.

Enclosure: *Functional Specification for the Smart Traffic Light*

Functional Specification for the Smart Traffic Light

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Issue Date: October 15, 2007

Revision: 1.0

Executive Summary

Current traffic lights are still susceptible to glare effects caused by the sun, which creates a hazard for motorists. Other weather related factors that reduce road visibility for motorists include fog. The Smart Traffic Light addresses the two issues by providing higher intensities of light when it senses the presence of direct sunlight over a specified threshold or fog. Also, our device consists of only one traffic lamp, as opposed to the standard triple lamp design, and will have the corresponding first letter of the illuminated color displayed, in order to enable people who suffer from color deficiency determine the state of the traffic light.

Due to critical tasks traffic lights perform, a high level of reliability is required and rigorous testing is essential to ensure that they conform to critical regulations. The main standard for traffic lights in North America is specified by the Institute of Transportation Engineers (ITE), and their standard dictates the minimum requirements for traffic lights. Due to pioneering nature of our device, we have specified several additional requirements for the STL in order to maintain a high standard of performance, reliability, and safety.

This document guides STL designers with regards to the required features and expected level of performance of the device. Though the requirements documented are exhaustive, it is by no means complete, due to the complexity of such systems. We shall continually revise and update the requirements in order to ensure that a satisfactory product is produced.

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Glossary

Duty Cycle. The fraction of time during a specified time period that the module is energized, expressed as a percent of the specified time period.

Lumens. A measure of the perceived power of light.

Nominal Operating Voltage. The Voltage**,** 120 VAC RMS, at which photometric and electrical performance requirements are specified.

Power Consumption. The electrical power in Watts consumed by the module when operated at nominal operating voltage and ambient operating temperature range.

Turn Off Time. The amount of time required after removal of the nominal operating voltage for the module to show no visible illumination.

Turn On Time. The amount of time required for the module to reach 90% of its full illumination**.**

Volt-Amperes. The product of root-mean-square (RMS) line voltage and RMS line current measured with true RMS meter.

Module. 14-inch (360 mm) round traffic signal indications. They consist of the light source and the lens (usually a sealed unit) that communicate movement messages (stop, caution or prepare to stop, and go) to drivers through red, yellow, and green colors.

Root mean square (**RMS**). A statistical measure of the magnitude of a varying quantity.

Ultraviolet (**UV**). An electromagnetic radiation with a wavelength shorter than that of visible light.

Wavelength. The distance between repeating units of a propagating wave within a given frequency.

01. Introduction

The Smart Traffic Light (STL) has the ability to sense fog and the intensity of ambient light, upon which it adjusts its lamp brightness accordingly, thereby consuming maximum power only when necessary. The STL will be largely compatible with current traffic light standards and will incorporate some existing glare prevention innovations. The STL also indicates the color of the illuminated lamp by displaying the symbol *R* for red, *G* for green, and *A* for amber as illustrated in Figure 1. The color of the illuminated lamp is indicated in order to enable people who suffer from color deficiency to distinguish the state of the traffic light.

Most of the requirements of the STL conform to the minimum requirements defined by the Institute of Transportation Engineering (ITE). However, the photometric requirements of the STL do not conform to that of the ITE, specified in section 4 of VTCSH-LED (Appendix), due to the use of a specialized technology.

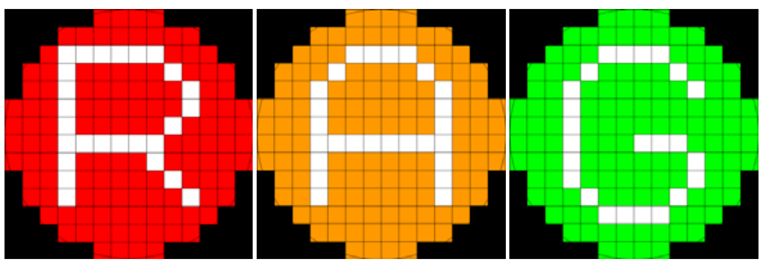

Figure 1: Appearances of Illuminated Traffic

1.1 Scope

This document specifies the requirements that must be met by the production model of the SGRTL. The prototype model of the STL needs only conform with the critical requirements specified in this document.

1.2 Intended Audience

This functional specification is intended for use by the design team at AnoLED Technology Inc., and streamlines the development process. If there is any uncertainty regarding the features of the STL, this document serves as a reference for clarification.

1.3 Classification

The requirements are labeled as [RXX.YY] in which XX represents the section number, and YY represents the item number.

02. Electrical Requirements

In addition to the electrical requirements specified in the traffic light standards manual (Appendix), we have compiled the following requirements for our device:

[R02.1] The module should include a class 2 power supply that can function using an input of 80 to 135 VAC at 60 ± 3 Hz.

[R02.2] The red light intensity of the lamp should at least be 1000 Lumens.

[R02.3] The amber light intensity of the lamp should at least be 2000 Lumens.

[R02.4] The red light intensity of the lamp should at least be 1500 Lumens.

[R02.5] Maximum power supplied to the red light source should not exceed 28 watts.

[R02.6] Maximum power supplied to the amber light source should not exceed 55 watts.

[R02.7] Maximum power supplied to the green light source should not exceed 43 watts.

[R02.8] The lamp should consume a nominal power of 17 Watts at 25°C, as well as a minimum power of 2.5 Watts, in the power efficiency mode at 25°C, when illuminated in red.

[R02.9] The lamp should consume a nominal power of 16 Watts at 25°C, as well as a minimum power of 3.5 Watts, in the power efficiency mode at 25°C, when illuminated in amber.

[R02.10] The lamp should consume a nominal power of 15 Watts at 25°C, as well as a minimum power of 3.5 Watts, in the power efficiency mode at 25°C, when illuminated in green.

[R02.11] The red light source shall have a wavelength between 615 to 705 nm [1].

[R02.12] The amber light source shall have a wavelength between 585 to 593 nm [1].

[R02.13] The green light source shall have a wavelength between 498 to 508 nm [1].

[R02.14] The lamp shall incorporate several similar light sources so as to increase the intensity of the illuminated area.

[R02.15] The light source should be designed such that any catastrophic failure of one light source does not affect the operation of other sources in a way that results in losing more than 5% of the illuminated intensity.

[R02.16] The fog detection system should include protective circuitry with automated reset.

03. Performance Requirements

[R03.1] The lamp modules must show symbols corresponding to the illuminated red, amber, or green colors, Figure 1.

[R03.2] Symbols must be illuminated in white color ranging from 2700 to 4200 K color temperatures depending upon the background ambient light.

[R03.3] The lamp modules must be capable of showing red, amber, and green arrows in left, right, or straight directions.

[R03.4] The intensity of output light from the lamp modules should be greater than the intensity of the ambient light.

[R03.5] The intensity of lamp modules is reduced during nights or cloudy days to provide a highly efficient mode of operation.

[R03.6] Decrease in visibility must be compensated by increase in intensity of the module.

[R03.7] The fog detection should detect up to 200 m.

[R03.8] For every 1°C increase in temperature beyond 80°C, the intensity of the lamp module must be reduced by 2%.

The system block diagram is illustrated in Figure 2, and it demonstrates the relation between the sensors and the light sources that are driven by the controller.

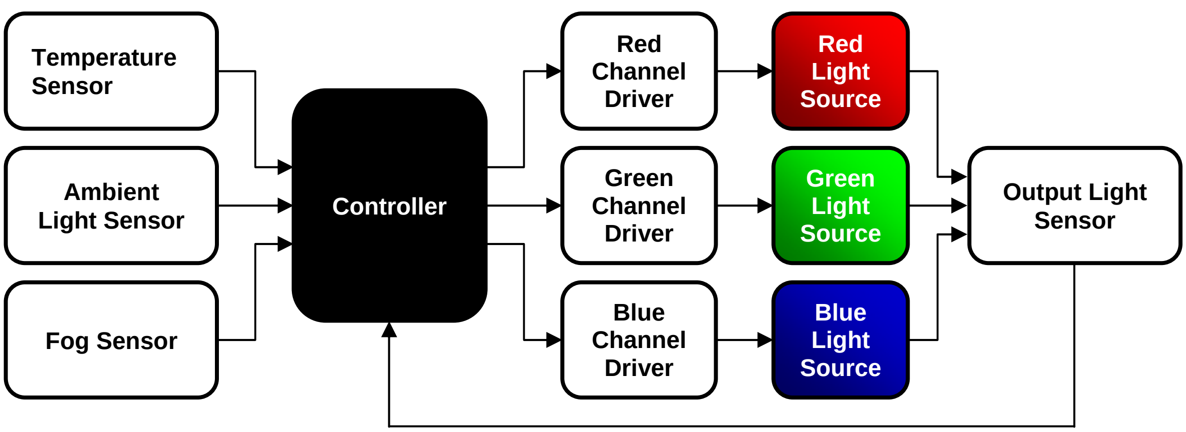

Figure 2: System Block Diagram

04. Safety Requirements

[R04.1] Duration of amber light is: 1 (sec) + braking deceleration time of 3 m/s^2.

[R04.2] All-red time is set so that a 6 m long vehicle travelling at the posted speed limit is able to clear the intersection.

[R04.3] The system is insulated to prevent risk of electric shock by external contact.

[R04.4] The system is secured and resistant to natural disasters such as earthquake, and tornado.

[R04.5] The casing of the module shall have smoothed edges to prevent any injuries.

[R04.6] The holding mast of the module should be completely secured in order to withstand tornados, floods and such.

[R04.7] The intensity produced by the module must not exceed the standards set by ITE.

[R04.8] A temperature sensor is to be employed inside the casing to alarm the user of any critical temperatures.

05. Compatibility Requirements

[R05.1] The light source of the modules are compatible with load switches to prevent overheat as well as LED flickering.

[R05.2] The module must be compatible with existing voltage feeds.

[R05.3] The module should be compatible with existing mountings and wirings.

[R05.4] The module should be compatible with most common power backup solutions such as solar panels.

06. Physical Requirements

[R06.1] The internal parts of the module should enable immediate dismantlement and replacement without further need of detachment of the module enclosure from the system.

[R06.2] The weight of the module shall not exceed 5kg.

[R06.3] The installation of the module shall be simple and relatively inexpensive.

The module shall include the following items:

- The module enclosure
- Lens
- Light source with its required components
- Fog detection sensor
- Ambient light sensor
- Thermal sensor
- Visor

Module Enclosure

[R06.4] The maximal measurements of the module should be 18” x 18” (457mm x 457mm).

[R06.5] The enclosure of the module should be a molded box of rigid plastic material.

[R06.6] The external enclosure parts of the module should be without corners or sharp edges that might inflict injury.

[R06.7] The finish of the external parts of the module should be non-reflective in order to avoid the reflection of the surroundings on the module.

[R06.8] The door of the module should be lockable and securely sealed.

[R06.9] The enclosure of the module should be closed in a manner that would enable opening and closing the door manually without tools.

[R06.10] All metal components such as screws, nuts, bolts and joints should be of galvanized metal or suitable plastic material.

[R06.11] There should be an opening of at least 30mm that shall enable attachment of the enclosure of the module and passage of the providing cables. With the exception of the top of the module, the opening can be located in any position on the module.

[R06.12] The module enclosure shall be attached in a manner that prevents them from relative rotation.

Lens

[R06.14] The lens should be transparent and allow uniform light scatter from the entire surface.

[R06.15] The lens should reflect a minimal amount of ambient lighting.

Lamp

[R06.16] The module shall be composed of one lamp with a diameter of 14” (356mm).

[R06.17] The lamp should be made of a material stabilized against UV radiation, as well as the color of the module.

Visor

[R06.18] A visor should be constructed on the module enclosure. It should be made of the same material as the module’s, with the same finish and a thickness of 3mm.

[R06.19] The visor shall be separated from the enclosure of the module in order to allow its replacement in the case of damage inflicted upon it.

[R06.20] All crevices and bulges required for connection of the visor and the enclosure of the module should be constructed in advance during the molding process.

[R06.21] When the visibility of the module needs to be limited in certain directions, visors will be assembled on it.

[R06.22] The visors shall be adapted to the special requirements of each module system.

[R06.24] The visors should be made of rigid material that shall prevent their deformation as a result of wind or overheating by the sun.

[R06.25] The color of the visor shall be identical to the color of the module enclosure, and its inner surface shall be black [3].

07. Environmental Requirements

[R07.1] The module should operate in temperatures between -40°C to 80°C.

[R07.2] The unit shall tolerate full range of atmospheric humidity.

[R07.3] It must be ice-resistant, water-proof and anti-dew.

[R07.4] Lens has to be of a material that reduces glare and sun reflection.

[R07.5] The module must be UV resistant.

[R07.6] The module shall reduce the effect of glare due to direct sun beam shone on the lamp area.

[R07.7] The module must withstand natural vibrations within the range specified in section 5 of this document.

[R07.8] Unit should have optimized power consumption and produce least waste material.

[R07.9] The fog detection system shall be sturdy, autonomous, and resistant to atmospheric conditions.

08. Reliability and Durability

[R08.1] The module should be able to perform continuously for 80,000 hours.

[R08.2] In the case of a failure, the module must have the ability of shutting itself off.

[R08.3] The module must be able to operate at a duty cycle of 100%, at an ambient temperature of 25°C, for at least 10 hours without failure.

[R08.4] The module must function within the input voltage range of 80 VAC RMS to 135 VAC RMS.

[R08.5] The module must have a protective mechanism against voltage and current surges.

[R08.6] Variations in the operating temperature of the module must not increase its power consumption by more than 30%.

[R08.7] The module must function in the presence of vibrations within the range of 2 to 120 Hz, at an acceleration of at least 2.5Gs.

[R08.8] The module must increase the intensity of its output light, comparing to conventional traffic lights, in the presence of fog.

[R08.9] The module must alter the intensity of its output light in accordance with the amount of direct sunlight sensed on the lamp surface.

[R08.10] The fog detection system should include a self diagnostic mode to check for performance errors.

09. Software Requirement

Should a programmable user interface be required, it must comply with the following requirements:

[R09.1] The program shall be reliable and be as error-free as possible.

[R09.2] The program should be portable and require minimal reprogramming in order to work within different environments.

[R09.3] The program should be expandable and reusable.

[R09.4] The program must be legible and contain appropriate comments.

[R09.5] The program must anticipate special cases and incompatibilities that may result in run-time errors, and produce appropriate error messages.

[R09.6] The program must be efficient and consume minimal system resources.

10. Marketing Requirement

[R10.1] The product should be aesthetically desirable.

[R10.2] It should have ruggedized packaging

[R10.3] The product should be flexible and cost-effective

[R10.4] The product should be marketed to customers who will utilize the full capabilities of the device.

11. User Documentation and Training

The Smart Traffic Light is to be installed by technicians and/or personnel with certain amount of expertise in the field and therefore the need for a more technical documentation is prominent. However, since STL is a new technology, AnoLED Technology has decided to produce a comprehensive and all-in-one installation, operation, and maintenance guide.

[R11.1] An all-in-one instructions booklet shall be provided and included in the item's packaging.

[R11.2] A programming guide shall be separately provided to the user upon request.

[R11.3] The manual will be in English, French, and Spanish so as to make it easier to comprehend in all North American countries.

[R11.5] A step-by-step troubleshooting guide shall be incorporated into the instructions booklet.

[R11.6] A regularly updated FAQ, Frequently Asked Questions, section will be available to the user via the website of the company.

[R11.7] A service manual shall be provided upon request at user's expense, in case the party is interested in servicing the device without handing the job over to authorize service personnel.

[R11.8] A "product features" demo and installation video will be uploaded on the company website. The user will also receive a copy on a DVD.

[R11.9] Warranty terms and conditions, as well as all company contact information are to be made available to the user both on the website and on a separate booklet called "Warranty Guide".

12. System Test Plan

Each module should be accompanied by a certifying document that indicates the module has passed conducted tests. Type of the test, the result of each test, name of the person who performed each test, and the serial number of the module must be included in the certifying document.

Prior to shipment, each module must be powered up for at least 24 hours, at its rated voltage, at 100% duty cycle, at an ambient temperature of 25°C ± 3°C.

Afterwards, each module should be tested at a temperature chamber that starts from the ambient temperature and reaches 74°C at a rate of 1°C per minute. The temperature will then decrease to -40°C at the same rate as above, and it will then increase to its initial ambient temperature.

While temperature varies, each module is switching among normal states; however, at its maximum illumination intensity, 100% duty cycle.

The second period of temperature variation is conducted while the input voltage of each module is varied within the rated voltage. While each module is switching among its operational states, the input voltage swings between its minimum and maximum allowed voltages, at a rate of 5 v/min.

Besides any permanent defects during the above tests, any identified illumination flickering that is more than a 10% variation of light intensity, and any unexpected change of illumination state shall identify the module as defective.

Power factor of each module should be measured by a commercially available power factor meter. If the requirements of section 5 of the Appendix document are not met, the module must be prohibited from shipment.

Mechanical vibration test should be conducted as defined by MIL-STD-883G, Test Method 2007.3, while sweeping frequency from 2 to 120 Hz, at an acceleration of 2.5Gs. A total number of three tests must be conducted, each of which along x, y, and z coordinate axes for a duration of 5 minutes.

Rain resistance and wind driven rain resistance of each module must be tested as specified by MIL-STD 810F, test Method 506.4. Each module should be placed vertically towards the wind source at 0° angle. The module will then be rotated about the vertical axis at a rate of 5° per minute, between -60° to 60°. The wind velocity could be up to 120 Km per hour.

The physical appearance of each module should be visually inspected. The lamp and the area surrounding it must be carefully inspected, and any identified cracks, discoloration, chips, or other defects must prevent the module form being shipped.

13. Conclusion

The requirements specified in this document are detailed and cover most aspects of the development of the STL, Smart Traffic Light.

The functional specification detailed herein, are mostly adopted from ITE's standard manual, VTCSH-LED. However, the photometric requirements of our device do not conform to section 4 of ITE's VTCSH-LED due to its application to a specific technology.

We have an experienced group member who has significantly accelerated product development. As planned, we will add two more stages to the project starting spring 2008 which is to be followed by the patent procedure.

The stages mentioned are to be evolved as the systems undergoes tests, and updates shall be released if required.

The target date for preliminary prototype demonstration is set for December 2007, and the design will be updated upon receiving feedback.

14. References

[1] Power Management Controls, "Power Indicator Colors and Accessibility,"
2001, http://eetd.lbl.gov/Controls/publications/P500-03-012F-AIV.pdf.

[2] Institute of Transportation Engineers, "Vehicle Traffic Control Signal Heads - Light Emitting Diode (LED) Circular Signal Supplement," June 2005, http://ite.org/standards/LEDSignalSupp8June05final1.pdf.

[3] Israel Ministry of Transport and Road Safety, "General Specification for Placement and Maintenance of Traffic Lights," Dec. 1993, http://www.mot.gov.il/wps/pdf/HE_TRAFFIC_PLANNING/PlacementMaintenanceTrafficLights.pdf.

15. Technical Appendices

Purchase Specification of the
Institute of Transportation Engineers

Vehicle Traffic Control Signal Heads -
Light Emitting Diode (LED) Circular Signal Supplement

Prepared by Joint Industry and Traffic Engineering Council Committee

June 8, 2005

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STANDARD ITE METRIC CONVERSION INSERT

During the service life of this document, use of the metric system in the United States is expected to expand. The following common factors represent the appropriate magnitude of conversion. This is because the quantities given in U.S. Customary units in the text, tables or figures, represent a precision level that in practice typically does not exceed two significant figures. In making conversions, it is important to not falsely imply a greater accuracy in the product than existed in the original dimension or quantity. However, certain applications such as surveying, structures, curve offset calculations, and so forth, may require great precision. Conversions for such purposes are given in parentheses.

Length
1 inch = 25 mm (millimeters—25.4)
1 inch = 2.5 cm (centimeters—2.54)
1 foot = 0.3 m (meters—0.3048)
1 yard = 0.91 m (0.914)
1 mile = 1.6 km (kilometers—1.61)

Volume
1 cubic inch = 16 cm^3 (16.39)
1 cubic foot = 0.028 m^3 (0.02831)
1 cubic yard = 0.77 m^3 (0.7645)
1 quart = 0.95 L (liter—0.9463)
1 gallon = 3.8 L (3.785)

Speed
foot/sec. = 0.3 m/s (0.3048)
miles/hour = 1.6 km/h (1.609)

Temperature
To convert °F (Fahrenheit) to °C (Celsius), subtract 32 and divide by 1.8.

Area
1 square inch = 6.5 cm^2 (6.452)
1 square foot = 0.09 m^2 (0.0929)
1 square yard = 0.84 m^2 (0.836)
1 acre = 0.4 ha (hectares—0.405)

Mass
1 ounce = 28 gm (gram—28.34)
1 pound = 0.45 kg (kilograms—0.454)
1 ton = 900 kg (907)

Light
1 footcandle = 11 lux (lumens per m^2—10.8)
1 footlambert = 3.4 cd/m^2 (candelas per m^2—3.426)

For other units refer to the American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohoken, PA 19428-2959, USA, *Standard for Metric Practices E 380.*

Vehicle Traffic Control Signal Heads - Light Emitting Diode (LED) Circular Signal Supplement - A Performance Specification of the Institute of Transportation Engineers, prepared by the ITE Joint Industry and Traffic Engineering Council Committee.

Members of the Joint Industry and Traffic Engineering Council Committee are: Nathaniel S. Behura, Transportation & Energy Solutions, Inc., Anaheim Hills, CA (Chair); Seth Chalmers, Chalmers Engineering Consultant, Tempe, AZ; Andrew Lipman, Next Generation Lighting, Chicago, IL; Henri R. Arcand, Consultant (GELcore), Pierrefond, Quebec, Canada; Gary R. Durgin, Dialight Corp., Farmingdale, NJ; David C. Edwards, Intertek Testing Services NA, Inc., Cortland, NY; Carl K. Andersen, FHWA, McLean, VA; James Cheeks, Staff Liaison, ITE, Washington, DC.

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Founded in 1930, the Institute serves as a gateway to knowledge and advancement through meetings, seminars, and publications; and through our network of more than 16,000 members working in some 90 countries. The Institute also has more than 70 local and regional chapters and more than 90 student chapters that provide additional opportunities for information exchange, participation, and networking.

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Publication No. ST-

Table of Contents

1. Purpose

The purpose of this specification is to provide the minimum performance requirements for 200 mm (8 in) and 300 mm (12 in) Light Emitting Diode (LED) vehicle traffic signal modules while in service. This specification is not intended to impose restrictions upon specific designs and materials that conform to the purpose and the intent of this specification. This specification refers to definitions and practices described in "Vehicle Traffic Control Signal Heads" published in the *Equipment and Materials Standards of the Institute of Transportation Engineers*, referred to in this document as "VTCSH." Until one year from the effective date of this specification, either the existing VTCSH Part 2 or these standards shall apply to all circular LED vehicle traffic signal modules (hereinafter "module" or "modules"). After one year from the effective date of this specification, only these standards shall apply to any purchased module. This specification is not restricted to any specific LED technology.

The requirements of this specification are based on the best information available at the time it was developed. It is the responsibility of the user and the module manufacturer to evaluate specific applications to insure that the requirements of a traffic control signal are met. Deviation from the performance standards provided in this specification should be documented in an engineering study.

2. Definitions

The following definitions are in addition to the definitions in the VTCSH.

2.1 Catastrophic Failure. The total loss of visible illumination from an LED light source.

2.2 Chromaticity. The color of the light emitted by a module, specified by the x, y chromaticity coordinates on the 1931 Commission Internationale d'Eclairage (CIE) chromaticity diagram.

2.3 Conditioning. Energizing a LED signal module at a specified ambient temperature for a specified period of time, to cause any early electronic component mortality failures to occur and to detect any component reliability problems.

2.4 Duty Cycle. The amount of time during a specified time period that a module is energized, expressed as a percent of the specified time period.

2.5 Hard Coat. A surface coating or film to provide front surface abrasion resistance.

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

2.7 LED Signal Module (module). A signaling unit comprised of an array of LEDs and related power supply, and any required lenses, which, when connected to appropriate power, provides a circular signal indication.

2.8 Luminance. The luminous flux emitted or reflected from a surface, in a given direction, per unit solid angle, divided by the area of the surface, expressed as cd/m^2.

2.9 Luminous Intensity. The luminous flux emitted in a given direction from a source, per unit solid angle, expressed in candelas (cd).

2.10 Minimum Maintained Luminous Intensity. The minimum luminous intensity a module is required to provide throughout service as a traffic control signal.

2.11 Nominal Operating Voltage. The AC RMS voltage, 120 VAC, at which photometric performance and power consumption are specified.

2.12 Power Consumption. The electrical power in Watts consumed by a module when operated at nominal operating voltage and ambient operating temperature range.

2.13 Power Factor. The power factor equals

Watts divided by Volt-Ampere or the ratio of power consumption in Watts to Volt-Amperes.

2.14 Total Harmonic Distortion (THD). THD is the ratio of the root-mean-square (RMS) value of the harmonics to the amplitude of the fundamental component of the AC waveform.

2.15 Translate. To move an object along a linear vector, such that the orientation of the object does not rotate relative to the original frame of reference.

2.16 Turn OFF Time. The amount of time required after removal of the nominal operating voltage for the LED signal module to show no visible illumination.

2.17 Turn OFF Voltage. The voltage below which the LED signal module emits no visible illumination.

2.18 Turn ON Time. The amount of time required for the LED signal module to reach 90% of full illumination.

2.19 Volt-Amperes. The product of the root-mean-square (RMS) line voltage and RMS line current, measured with true RMS meters.

3. Physical & Mechanical Requirements

3.1 General

3.1.1 Modules shall fit into existing traffic signal housings built to the VTCSH Standard without modification to the housing, or shall be stand-alone units that incorporate a housing meeting the performance and design requirements of the VTCSH Standard.

3.1.2 Installation of a module into an existing signal housing shall not require the use of special tools. The module shall connect directly to existing electrical wiring system.

3.2 LED Signal Module

3.2.1 A module shall be capable of replacing the existing optical components or signal module in a signal housing, or shall provide a complete replacement of the signal head.

3.2.2 The module lens shall be hard coated or otherwise made to comply with the material exposure and weathering effects requirements of the Society of Automotive Engineers (SAE) J576.

3.2.3 Tinting (Optional) - The lens may be tinted or covered by transparent film or materials with similar color and transmissive characteristics.

3.2.4 The module lens may be a replaceable part, without the need to replace the complete LED signal module.

3.3 Environmental Requirements

3.3.1 All exposed components of a module shall be suitable for prolonged exposure to the environment, without appreciable degradation that would interfere with function or appearance. As a minimum, selected materials shall be rated for service for a period of a minimum of 60 months in a south-facing Arizona Desert installation.

3.3.2 A module shall be rated for use throughout an ambient operating temperature range, measured at the exposed rear of the module, of -40°C (-40°F) to +74°C (+165°F).

3.3.3 A module shall be protected against dust and moisture intrusion, including rain and blowing rain.

3.3.4 The module lens shall not crack, craze or yellow due to solar UV irradiation typical for a south-facing Arizona Desert installation after a minimum of 60 months in service.

3.4 Construction

3.4.1 A module shall be a self-contained device, not requiring on-site assembly for installation into an existing traffic signal housing. The power supply for the module may be either integral or packaged as a separate component. The power supply may be designed to fit and mount inside the traffic signal housing adjacent to the LED signal module.

3.4.2 Assembly and manufacturing processes for a module shall be designed to assure all internal LED and electronic components are adequately supported to withstand mechanical shock and vibration due to high winds and other sources.

3.5 Materials

3.5.1 Materials used for the lens and module construction shall conform to ASTM specifications for the materials, where applicable.

3.5.2 Enclosures containing either the power supply or electronic components of the signal module shall be made of UL94 flame retardant materials. The module lens is excluded from this requirement.

3.6 Module Identification

3.6.1 Each module shall be identified on the backside with the manufacturer's name, model, operating characteristics and serial number. The operating characteristics identified shall include the nominal operating voltage and stabilized power consumption, in watts and Volt-Amperes.

3.6.2 Modules and removable lenses shall have a prominent and permanent vertical indexing indicator, i.e., UP Arrow, or the word UP or TOP, for correct indexing and orientation in the signal housing.

3.6.3 Modules conforming to all non-optional requirements of this specification may have the following statement on an attached label: "Manufactured in Conformance with the ITE LED Circular Signal Supplement."

4. Photometric Requirements

4.1 Luminous Intensity, Uniformity & Distribution

4.1.1 Minimum maintained luminous intensity: When operated under the conditions defined in Sections 3.3.2 and 5.2.1, the luminous intensity values for modules shall not be less than the values calculated using the method described below for a minimum period of 60 months.

4.1.1.1 Calculate the vertical intensity factor ($f(I_{Vert})$) for the range from 12.5 degrees up (+12.5) to 27.5 degrees down (-27.5), using the appropriate equation:

For $\theta_{Vert} > -2.5$ degrees:

$$f\left(I_{Vert}\right) = 0.05+0.9434*e^{-\left(\frac{\theta_{Vert}+2.5}{5.3}\right)}$$

For $\theta_{Vert} \le -2.5$ degrees:

$$f\left(I_{Vert}\right) = 0.26+\left(\frac{\theta \text{Vert}}{143}\right)+0.76*\left[e^{-0.02\left(\theta_{Vert}+2.5\right)^2}\right]^{\left(-0.07*\theta_{Vert}\right)}$$

where: θ_{Vert} is the angle measured above or below a horizontal plane perpendicular to the face of the module lens. (Note: angles above the horizontal plane are positive, while angles below the horizontal plane are negative.)

4.1.1.2 Calculate the horizontal intensity factor ($f(I_{Horiz})$) for the range from 27.5 degrees left to 27.5 degrees right:

$$f\left(I_{Horiz}\right) = 0.05+\left(0.95*e^{\left(-\frac{1}{2}*\left(\frac{\theta_{Horiz}}{11}\right)^2\right)}\right)$$

where: θ_{Horiz} is the angle measured from a vertical plane to the left or right, perpendicular to the face of the module lens.

4.1.1.3 Select the appropriate peak minimum maintained luminous intensity value for the specified module size and color:

Peak minimum maintained luminous intensity values, at θ_{Vert} = –2.5 deg and θ_{Horiz} = 0 deg [$\mathbf{I_{(-2.5, 0)}}$], by size and color of the module are:

Color	$\mathbf{I_{(-2.5, 0)}}$ 200mm	300mm
Red	165 cd	365 cd
Yellow	410 cd	910 cd
Green	215 cd	475 cd

4.1.1.4 Multiply the vertical intensity factor times the horizontal intensity factor (for the selected pair of angles). Round the result to two significant figures, and multiply the combined angular intensity factor times the peak minimum maintained luminous intensity value for the appropriate signal size and color:

$$I_{(\theta vert,\ \theta horiz,\ size,\ color)} = [f(I_{Vert})^* f(I_{Horiz})]^* I_{(-2.5,\ 0)}$$

The resultant value of the luminous intensity shall be rounded to the nearest whole number.

Example: What is the minimum maintained luminous intensity value for a green, 300 mm LED signal light at 5 degrees down and 10 degrees left?

$$I_{(-5,\ 10,\ 300,\ Green)} = [f(I_{vert = -5})^* f(I_{horiz = 10})]^* 475 \text{ cd}$$

$$I_{(-5,\ 10,\ 300,\ Green)} = [0.953^*0.678]^*475 \text{ cd}$$

$$I_{(-5,\ 10,\ 300,\ Green)} = 0.65^*475 = 309 \text{ cd}$$

4.1.1.5 Table 1 provides the minimum maintained luminous intensity values, over the required angular range, at 5-degree increments. Note that the horizontal limitations vary for various vertical angles (e.g.: at θ_{Vert} = +12.5 degrees, requirements are only specified from 7.5 degrees right to 7.5 degrees left, while at θ_{Vert} = -12.5 degrees, the horizontal limitations are from 27.5 degrees right to 27.5 degrees left). Table 2 provides the minimum maintained luminous intensity values, over the required angular range, at 2.5-degree increments. Tables 1 and 2 are provided to illustrate the minimum required values at certain specific angles within the required angular range of performance (i.e. while testing for light output compliance of a module in a laboratory, an agency may use Table 1, and/or other specific pairs of vertical and horizontal angles of its choosing within the required angular range.) One must use the procedure outlined above for determining the minimum maintained luminous intensity values at any specific pairs of vertical and horizontal angles within the required angular range.

4.1.2 Maximum permissible luminous intensity: When operated within the temperature range specified in Section 3.3.2, the actual luminous intensity for a module shall not exceed three times the required peak value of the minimum maintained luminous intensity for the selected signal size, and color.

4.1.3 Luminance uniformity: The uniformity of the signal output across the entire module lens shall not exceed a ratio of 10 to 1 between the maximum and minimum luminance values (cd/m^2).

4.2 Chromaticity

4.2.1 Color regions: The measured chromaticity coordinates of modules shall conform to the following color regions, based on the 1931 CIE chromaticity diagram (see Figure 1):

Red: $y = 0.308$;
$y = 0.953 - 0.947x$;
$y = 0.290$:

Point	Red *x*	*y*
1	0.692	0.308
2	0.681	0.308
3	0.700	0.290
4	0.710	0.290

Yellow: $y = 0.151 + 0.556x$;
$y = 0.972 - 0.976x$;
$y = 0.235 + 0.300x$:

Point	Yellow *x*	*y*
1	0.545	0.454
2	0.536	0.449
3	0.578	0.408
4	0.588	0.411

Green: $y = 0.655 - 0.831x$
$x = 0.150$;
$y = 0.422 - 0.278x$:

Point	Green x	Green y
1	0.005	0.651
2	0.150	0.531
3	0.150	0.380
4	0.022	0.416

4.2.2 Color uniformity: The dominant wavelength for any individual color measurement of a portion of the emitting surface of a module shall be within ±3nm of the dominant wavelength for the average color measurement of the emitting surface as a whole.

5. Electrical

5.1 General

All wiring and terminal blocks shall meet the requirements of Section 13.02 of the VTCSH standard. Two secured, color coded, 600V, jacketed wires, a minimum of 20 AWG and at least 1 meter (39 in) in length, conforming to the NFPA 70, National Electrical Code, and rated for service at +105°C, shall be provided.

5.2 Voltage Range

5.2.1 LED signal modules shall operate from a 60±3 Hz AC line power over a voltage range from 80 to 135 VAC RMS.

5.2.2 Fluctuations in line voltage over the range of 80 to 135 VAC shall not affect luminous intensity by more than ±10 percent.

5.2.3 The module circuitry shall prevent flicker of the LED output at frequencies less than 100 Hz over the voltage range specified in Section 5.2.1.

5.2.4 Low Voltage Turn OFF: There shall be no visible illumination from the LED signal module when the applied voltage is less than 35 VAC.

5.2.5 Turn-ON and Turn-OFF Time: A module shall reach 90% of full illumination (turn-ON) within 75 msec of the application of the nominal operating voltage. The signal shall cease emitting visible illumination (turn-OFF) within 75 msec of the removal of the nominal operating voltage.

5.3 Transient Voltage Protection

The on-board circuitry of a module shall include voltage surge protection, to withstand high-repetition noise transients and low-repetition high-energy transients as stated in Section 2.1.8, NEMA Standard TS 2-2003[1].

5.4 Electronic Noise

The LED signal and associated on-board circuitry shall meet the requirements of the Federal Communication Commission (FCC) Title 47, Subpart B, Section 15 regulations concerning the emission of electronic noise by Class A digital devices.

5.5 Power Factor and AC Harmonics

5.5.1 Modules shall provide a power factor of 0.90 or greater when operated at nominal operating voltage, and 25ºC (77ºF).

5.5.2 Total harmonic distortion induced into an AC power line by a module at nominal operating voltage, and at 25ºC (77ºF), shall not exceed 20%.

5.6 Controller Assembly Compatibility

5.6.1 The current draw shall be sufficient to ensure compatibility and proper triggering and operation of load current switches and conflict monitors in signal controller units.

5.6.2 Off State Voltage Decay: When the module is switched from the On state to the Off state the terminal voltage shall decay to a value less than 10 VAC RMS in less than 100 milliseconds when driven by a maximum allowed load switch leakage current of 10 milliamps peak (7.1 milliamps AC).

5.7 Failed State Impedance

[1] The ITE LED Traffic Signal Specification Committee has requested NEMA to review the requirements for transient voltage protection and testing for LED traffic signal modules. Currently NEMA is reviewing these requirements. Amendments or updates, *if necessary*, will be made to this section when the review is complete.

The module shall be designed to detect catastrophic loss of the LED load. Upon sensing the loss of the LED load, the module shall present a resistance of at least 250 kΩ across the input power leads within 300 msec. The LED light source will be said to have failed catastrophically if it fails to show any visible illumination when energized according to Section 5.2.1 after 75 msec.

5.8 Nighttime Dimming (Optional)

5.8.1 When requested, the module circuitry shall allow a reduction of the intensity of the light output in response to an input from the traffic signal controller.

5.8.2 Dimming, if provided, shall reduce light output to levels established to match ambient lighting conditions. Dimming may be in stepped increments or may be continuously variable. The minimum light output, when dimmed, shall not be less than 30% of the minimum maintained luminous intensity, as defined in Section 4.1.1.

6. Quality Assurance

6.1 General

6.1.1 Quality Assurance Program: 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 modules built to meet this specification.

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

6.1.3 Conformance: Module designs not satisfying design qualification testing and the production quality assurance testing performance requirements in Sections 6.3 and 6.4 shall not be labeled, advertised, or sold as conforming to this specification.

6.2 Manufacturers' Serial Numbers

Each module shall be identified with the information specified in paragraph 3.6.1.

6.3 Production Tests & Inspections

6.3.1 Production Test Requirements: All modules tendered for sale shall undergo the following Production Testing & Inspection prior to shipment. Failure of a module to meet the requirements of Production Testing & Inspection shall be cause for rejection. Test results shall be maintained per the requirement of Section 6.1.2.

6.3.1.1 All Production Tests shall be performed at an ambient temperature of 25ºC (77ºF) and at the nominal operating voltage of 120 VAC.

6.3.2 Luminous Intensity: All modules shall be tested for luminous intensity. A single point measurement, with a correlation to the intensity requirements of Sections 4.1.1 and 4.1.2 may be used. The purchaser may specify additional measurements. Failure of a module to meet the requirements for minimum maintained luminous intensity (4.1.1) or maximum permissible luminous intensity (4.1.2) shall be cause for rejection of the module.

6.3.3 Power Factor: All modules shall be tested for power factor per the requirements of Section 5.5.1. A commercially available power factor meter may be used to perform this measurement. Failure of a module to meet the requirements for power factor (5.5.1) shall be cause for rejection of the module.

6.3.4 Current Consumption Measurement: All modules shall be measured for current flow in Amperes. The measured current values shall be compared against the design current values from design qualification measurements in Section 6.4.6.1. A measured current consumption in excess of 120% of the design qualification current value for an ambient temperature of 25ºC (77ºF) shall be cause for rejection of the module.

6.3.5 Visual Inspection: All 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. The presence of any such defects shall be cause for rejection of the module.

6.4 Design Qualification Testing

6.4.1 Design Qualification Test Requirements. Design qualification testing shall be performed on new module designs, when a major design change has been implemented on an existing design, or after every 5 years that a design is in service. Modules used in design qualification testing shall be representative of the manufacturer's proposed normal production. If modules are provided with both clear and tinted lenses, the tests for Temperature Cycling (6.4.3.2), Moisture Resistance (6.4.3.3), Luminous Intensity (6.4.4.1), Luminance Uniformity (6.4.4.5), Chromaticity (6.4.4.6), Color Uniformity (6.4.4.7), and Lens Abrasion (6.4.5.2) shall be conducted for all lens types. The certification of UV Stabilization (6.4.5.2) shall be provided for all materials used in or on the emitting lenses.

6.4.1.1 Test data shall be retained by the manufacturer in accordance with Section 6.1.2, or for 60 months following final production of a specific design, whichever is longer.

6.4.1.2 Six modules shall be used in Design Qualification Testing. All six modules shall be subjected to conditioning (6.4.2), followed by the Environmental Tests (6.4.3). Following the Environmental Tests, three modules shall undergo Photometric & Colorimetric Tests (6.4.4), followed by the Lens Tests (6.4.5). The remaining three modules shall undergo the Electrical Tests (6.4.6), the Controller Assembly Compatibility Tests (6.4.7), and the Failed State Impedance Test (6.4.8). Tests shall be conducted in the order described herein, unless otherwise specified. Figure 2 provides a flow chart for the Design Qualification Testing.

6.4.1.3 In order for a module design to be considered acceptable for marking with the label described in 3.6.3, all tested modules must comply with the acceptance/rejection criteria for the Environmental Tests (6.4.3), Photometric & Colorimetric Tests (6.4.4), Lens Tests (6.4.5), Electrical Tests (6.4.6), Controller Assembly Compatibility Tests (6.4.7), and the Failed State Impedance Test (6.4.8).

6.4.2 Conditioning: Modules shall be energized for a minimum of 24 hours, at 100% duty cycle, in an ambient temperature of +60°C (+140°F).

6.4.3 Environmental Tests:

6.4.3.1 Mechanical Vibration: Mechanical vibration testing shall be performed per MIL-STD-883, Test Method 2007, using three 4 minute cycles along each x, y, and z axis, at a force of 2.5 Gs, with a frequency sweep from 2 Hz to 120 Hz.

6.4.3.2 Temperature Cycling: Temperature cycling shall be performed per MIL-STD-883, Test method 1010. The temperature range shall include the full ambient operating temperature range specified in 3.3.2. 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 extreme temperature. Signals under test shall be non-operating.

6.4.3.3 Moisture Resistance: Moisture resistance testing shall be performed per MIL-STD-810F, Test Method 506.4, Procedure I, Rain and Blowing Rain. The test shall be conducted on stand-alone modules, without a protective housing. The rainfall rate shall be 1.7 mm/min (4 in/hr) and droplet size shall predominantly be between 0.5 mm and 4.5 mm (0.02 to 0.18 in). The modules shall be vertically oriented, such that the lens is directed towards the wind source when at a zero rotation angle. The module shall be rotated at a rate of 4 degrees per minute along the vertical axis, from an orientation of –60 to +60 degrees during the test. The duration of the test shall be 30 minutes. The modules shall be energized throughout the test. The water shall be at 25° ± 5°C (77° ± 9°F). The wind velocity shall be 80 km/hr (50 mph). If the module is equipped with a remote power supply unit, then the test shall be conducted with the remote power supply unit attached to the clamping device holding the module to the test apparatus.

6.4.3.4 Environmental Tests Evaluation: At the conclusion of the Environmental Tests, all the modules will be visual inspected for damage and energized to insure proper operation.

6.4.3.5 Acceptance/Rejection Criteria: The loosening of the lens, or any internal components, or evidence of other physical damage, such as cracking of the module lens or housing, or presence of internal moisture, or failure to operate correctly after testing shall be considered a failure of the design.

6.4.4 Photometric & Colorimetric Tests: Three of the modules that were subjected to the Environmental Tests shall undergo Photometric & Colorimetric Tests. Unless otherwise specified, these tests shall be performed with the modules energized at nominal operating voltage.

6.4.4.1 Luminous intensity at standard temperature: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity at a temperature of 25°C (77°F). Measurements shall be made for all angular combinations specified in Table 1, or at other angles, as specified by the purchaser.

6.4.4.1.1 Luminous intensity measurements for red and green signal modules shall be made after the signal module has been operated under the test conditions for a minimum of 60 minutes at a 100% duty cycle.

6.4.4.1.2 Luminous intensity measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible.

6.4.4.2 Luminous intensity at low voltage: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity when operated at 80 VAC at a temperature of 25°C (77°F). A single-point correlation measurement of the luminous intensity, in the region from 0 to 7.5 degrees down, and from 7.5 degrees left to 7.5 degrees right shall be recorded. The single-point measurement shall be correlated to the measurement made in the same direction under Section 6.4.4.1 to generate a full range of luminous intensity values at reduced voltage. The luminous intensity measurement at reduced voltage shall be made immediately following measurements for luminous intensity at standard temperature (6.4.4.1), and following the same procedures as in 6.4.4.1.1 and 6.4.4.1.2.

6.4.4.3 Luminous intensity at elevated voltage: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity when operated at 135 VAC at a temperature of 25°C (77°F). A single-point correlation measurement of the luminous intensity, in the region from 0 to 7.5 degrees down, and from 7.5 degrees left to 7.5 degrees right shall be recorded. The single-point measurement shall be correlated to the measurement made in the same direction under Section 6.4.4.1 to generate a full range of luminous intensity values at elevated voltage. The luminous intensity measurement at elevated voltage shall be made immediately following measurements for luminous intensity at reduced voltage (6.4.4.2). and following the same procedures as in 6.4.4.1.1 and 6.4.4.1.2.

6.4.4.4 Luminous intensity at high temperature: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity at a temperature of 74ºC (165ºF). The modules shall be mounted in a temperature chamber so that the lens is outside the chamber and all portions behind the lens are within the chamber at a temperature of 74ºC (165ºF). The air temperature in front of the lens shall be maintained at a minimum of 49°C (120°F) during all tests. A single-point correlation measurement of the luminous intensity, in the region from 0 to 7.5 degrees down, and from 7.5 degrees left to 7.5 degrees right shall be recorded. The single-point measurement shall be correlated to the 25°C (77°F) measurement made in the same direction under Section 6.4.4.1 to generate a full range of luminous intensity values at high temperature.

6.4.4.4.1 Luminous intensity measurements for red and green signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 100% duty cycle.

6.4.4.4.2 Luminous intensity measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible.

6.4.4.5 Luminance uniformity: The modules shall be tested for compliance with the requirements for luminance uniformity at a temperature of 25°C (77°F). Measurements shall be made using a luminance meter located on the physical axis of the module lens at a distance such that the selected aperture samples a spot size of 25mm (1 inch) at the lens surface. The position of the luminance meter shall be translated from side to side and up and down, so as to sample the entire emitting surface of the module. The highest and lowest values of luminance shall be recorded. These measurements may be made immediately following measurements for luminous intensity at standard temperature and elevated voltage (6.4.4.3), after returning the voltage to the nominal operating voltage (120VAC).

6.4.4.5.1 Luminance uniformity measurements for the green and red signals must be made with the signal module operating at a 100% duty cycle. Therefore, it is necessary for the signal module under test to reach thermal equilibrium, and for the output to be stable prior to taking measurements.

6.4.4.5.2 Measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible.

6.4.4.6 Chromaticity: The chromaticity of the emitted light from modules shall be measured at a temperature of 25°C (77°F). A spectro-radiometer with a maximum bandwidth of 4nm, or a colorimeter that has a measurement uncertainty of less than 2.5% over the emission spectra of the module, shall be used for this measurement. The spectro-radiometer or colorimeter shall be located on the physical axis of the module lens at a distance such that the selected aperture samples a spot size of 25mm (1 inch) at the lens surface. The meter shall be translated from side to side and up and down, so as to sample a minimum of nine equally distributed positions about the emitting surface of the module. The colorimetric values of the emitted light at each of the nine positions shall be recorded, and an average value calculated, based on the CIE Standard 2° Observer. These measurements may be made immediately following measurements for luminance uniformity (6.4.4.5).

6.4.4.6.1 Chromaticity measurements for the green and red signals must be made with the signal module operating at a 100% duty cycle. Therefore, it is necessary for the signal module under test to reach thermal equilibrium, and for the output to be stable prior to taking measurements.

6.4.4.6.2 Measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible. If necessary, the ON interval may be extended to 10 seconds to permit completion of a measurement. The duty cycle between individual measurements, however, shall remain 12.5%, with a 5 second ON interval.

6.4.4.7 Color uniformity: The average and nine individual sets of chromaticity values of each module under evaluation shall be plotted on the CIE 1931 Chromaticity Diagram (see Figure 1).

6.4.4.8 Photometric & Colorimetric Tests Evaluation: At the conclusion of the Photometric & Colorimetric Tests, the measurement data shall be compared to the applicable requirements of Sections 4.1 and 4.2.

6.4.4.9 Acceptance/Rejection Criteria: The failure of any module to meet the requirements for minimum maintained luminous intensity (4.1.1) or maximum permissible luminous intensity (4.1.2) under standard and high temperatures, the requirement for luminance uniformity (4.1.3) and/or the appropriate requirement for chromaticity (4.2) shall be considered a failure of the proposed design.

6.4.5 Lens Tests: Following the Photometric & Colorimetric Tests, the three modules shall be subjected to the following tests of the acceptability of the lens construction.

6.4.5.1 UV Stabilization: Documentation shall be provided that certifies that the loss of direct transmission through the lens shall not cause the performance of the module to fall below the photometric requirements, or deviate from the colorimetric requirements of this specification after 60 months, or greater as specified by the manufacturer, of service in accordance with 3.3.1 and 3.3.4. Documentation shall be provided for hard-coat film (if used), tinting film or material (if used) and lens material.

6.4.5.2 Lens Abrasion Test: Abrasion resistance testing of the module lens shall be performed as follows:

a) A lens shall be mounted in the abrasion test fixture with the lens facing upwards.

b) An abrading pad meeting the requirements in paragraphs c) through f) below shall be cycled back and forth (1 cycle) for 12 cycles at 10cm ± 2cm per second over the whole surface of the lens.

c) The abrading pad shall be not less than 2.5cm ± 0.1cm square, constructed of 0000 steel wool and rubber, cemented to a rigid base shaped to the same contour as the lens. The "grain" of the pad shall be perpendicular to the direction of motion.

d) The abrading pad support shall be equal in size to the pad and the center of the support surface shall be within ± 2mm of parallel to the lens surface.

e) The density of the abrading pad shall be such that when the pad is mounted to its support and is resting unweighted on the lens, the base of the pad shall be no closer than 3.2mm to the lens at its closest point.

f) When mounted on its support and resting on the lens, the abrading pad shall be weighted such that a pad pressure of 14 kPa ± 1kPa exists at the center and perpendicular to the face of the lens.

g) A pivot shall be used if required to follow the contour of the lens.

h) Unused steel wool shall be used for each test.

6.4.5.3 Acceptance/Rejection Criteria: The photometric performance of a module following the lens abrasion test shall be 90% or more of the photometric performance of the same module measured prior to the lens abrasion test. A single point correlation as described in paragraph 6.4.4.4 may be used to determine the change in photometric performance. Failure of any module to meet the requirement for photometric performance following the lens abrasion test shall be considered a failure of the proposed design.

6.4.6 Electrical Tests: Three of the modules that were subjected to the Environmental Tests shall undergo Electrical Tests. These tests shall be performed with the modules energized at nominal operating voltage and at a standard temperature of 25°C (77°F), unless specified otherwise.

6.4.6.1 Current Consumption: The current flow, in Amperes, shall be measured at various ambient temperatures across the span of the operating temperature range specified in 3.3.2. The manufacturer shall provide information (charts, tables and/or graphs) on the variation in current through 60 months of service, or greater as specified by the manufacturer, within the operating temperature range of 3.3.2. In addition, the current consumption at start-up shall be measured at 25°C (77°F) to establish the reference value used for Production Quality Assurance (6.3.4).

6.4.6.2 Low-Voltage Turn-OFF: The modules shall be connected to a variable power supply, and energized at nominal operating voltage. The applied voltage shall be reduced to a point where there is no visible illumination from the module when the background is at an average luminance of 0.1 cd/m^2 (0.01 ft-cd).

6.4.6.3 Turn-ON/Turn-OFF Times: Using a two-channel oscilloscope, the time delay between application of nominal operating voltage and the module reaching 90% of full light output, and the time delay between de-energizing the module and the light output dropping to 0% of full output, shall be measured.

6.4.6.4 Transient Voltage Immunity: The modules shall be tested for transient immunity using the procedure described in Section 2.1.8, NEMA Standard TS 2-2003.

6.4.6.5 Electronic Noise: The modules shall be tested for conformance with the requirements of a Class A digital device, as specified in FCC Title 47, Subpart B, Section 15.109(b).

6.4.6.6 Power Factor: The power factor for the modules shall be measured and recorded. A commercially available power factor meter may be used to perform this measurement.

6.4.6.7 Total Harmonic Distortion (THD): The THD induced into an AC power line by the modules shall be measured and recorded. A commercially available total harmonic distortion meter may be used to perform this measurement.

6.4.6.8 Electrical Tests Evaluation: At the conclusion of the Electrical Tests, the measurement data shall be compared to the requirements of Sections 5.2 through 5.5.

6.4.6.9 Acceptance/Rejection Criteria: The failure of any module to meet the requirements for low-voltage turn-OFF (5.2.4), turn-ON/turn-OFF times (5.2.5), transient voltage immunity (5.3), emission of electronic noise (5.4), minimum power factor (5.5.1), and/or maximum total harmonic distortion (5.5.2) shall be considered a failure of the proposed design.

6.4.7 Controller Assembly Compatibility Tests: Following the Electrical Tests, three modules shall be tested for compatibility with load current switches and conflict monitors presently in service. The manufacturer shall test the design for the specific type signal control unit with which the design is intended to be compatible.

6.4.7.1 Load Switch Compatibility: The modules shall be tested for compatibility and proper operation with load current switches. Each module shall be connected to a variable AC voltage supply. The AC line current into the module shall be monitored for sufficient current draw to ensure proper load switch operation while the voltage is varied from 80 to 135 VAC.

6.4.7.2 Off State Voltage Decay Test: Each module shall be operated from a 135 VAC voltage supply. A 19.5 kΩ resistor shall be wired in series in the hot line between the module and the AC power supply. A single-pole-single-throw switch shall be wired in parallel with the 19.5 kΩ resistor. A 220 kΩ shunt resistor shall be wired between the hot line connection and the neutral line connection on the module. Conflict monitor Off state impedance compatibility shall be tested by measuring the voltage decay across the 220 kΩ shunt resistor as follows: The single-pole-single-throw switch shall be closed, bypassing the 19.5 kΩ resistor and allowing the AC power supply to energize the module. Next, the switch shall be opened and the voltage across the 220 kΩ shunt resistor shall be measured for decay to a value equal to or less than 10 VAC RMS. The test shall be repeated 10 times, with the longest decay time recorded as the final test value.

6.4.7.3 Controller Assembly Compatibility Tests Evaluation: At the conclusion of the Controller Assembly Compatibility Tests, the measurement data shall be compared to the requirements of Section 5.6.

6.4.7.4 Acceptance/Rejection Criteria: Failure of the module to draw sufficient current to ensure compatibility with the load current switches in the appropriate Controller Assembly (5.6.1) and/or failure of the circuit voltage to decay to a value equal to or less than 10 VAC RMS within a time period equal to or less than 100 milliseconds (5.6.2) shall be considered a failure of the proposed design.

6.4.8 Failed State Impedance Test: The modules shall be tested for compliance with the requirement for provision of a failed-state impedance (5.7). The test is conducted in two parts: first the module is energized with the LED load disconnected from the power supply to establish the failed-state impedance. Next, the requirement for the failed state impedance is tested. The module shall be operated from a 120 VAC voltage supply.

a) Wire a 50 kΩ resistor in series with the hot line between the module and the AC power supply. A 100 kΩ shunt resistor shall be wired between the hot line connection and the neutral line connection on the module. A single-pole-single-throw switch shall be wired in parallel with the 50 kΩ resistor. With the switch in the closed position and the LED load disconnected from the module power supply, energize the module for 300ms to establish the failed state impedance (5.7.2).

b) The second part of the failed state impedance test is conducted to insure that the appropriate failed state impedance is established. The switch is opened and the circuit is energized by the 120VAC voltage supply. The voltage across the 100 kΩ shunt resistor shall be continuously monitored. The voltage shall decay to a value equal to or greater than 70 VAC RMS. For the continuous interval of 500 ms through 1500 ms, after energizing the circuit with an open switch, the measured voltage shall be 70 VAC RMS or greater. The second part of the test shall be repeated 10 times, with the minimum voltage recorded during the continuous interval of 500 ms through 1500 ms, after energizing the circuit with an open switch, recorded as the final test value.

6.4.8.1 Failed State Impedance Test Evaluation: At the conclusion of the Failed State Impedance Test, the measurement data shall be compared to the requirement of Section 5.7.

6.4.8.2 Acceptance/Rejection Criteria: Failure of the voltage across the 100 kΩ shunt resistor to remain at a value equal to or greater than 70 VAC RMS for the continuous time interval of 500 ms through 1500 ms, after energizing the circuit with an open switch, shall be considered a failure of the proposed design.

Table 1

Table 1 provides the minimum maintained luminous intensity values for the VTCSH LED Circular Signal, for the range from 12.5 degrees above to 22.5 degrees below the horizontal plane, and from 27.5 degrees left to 27.5 degrees right of the vertical plane, at 5 degree increments.

Minimum Maintained Luminous Intensity Values—VTCSH LED Circular Signal

Vertical Angle	Horizontal Angle	Luminous Intensity (candela)					
		200mm (8-inch)			300 mm (12-inch)		
		Red	Yellow	Green	Red	Yellow	Green
+12.5	2.5	17	41	22	37	91	48
	7.5	13	33	17	29	73	38
+7.5	2.5	31	78	41	69	173	90
	7.5	25	62	32	55	137	71
	12.5	18	45	24	40	100	52
+2.5	2.5	68	168	88	150	373	195
	7.5	56	139	73	124	309	162
	12.5	38	94	49	84	209	109
	17.5	21	53	28	47	118	62
	22.5	12	29	15	26	64	33
-2.5	2.5	162	402	211	358	892	466
	7.5	132	328	172	292	728	380
	12.5	91	226	118	201	501	261
	17.5	53	131	69	117	291	152
	22.5	28	70	37	62	155	81
	27.5	15	37	19	33	82	43
-7.5	2.5	127	316	166	281	701	366
	7.5	106	262	138	234	582	304
	12.5	71	176	92	157	391	204
	17.5	41	103	54	91	228	119
	22.5	21	53	28	47	118	62
	27.5	12	29	15	26	64	33
-12.5	2.5	50	123	65	110	273	143
	7.5	40	98	52	88	218	114
	12.5	28	70	37	62	155	81
	17.5	17	41	22	37	91	48
	22.5	8	21	11	18	46	24
	27.5	5	12	6	11	27	14
-17.5	2.5	23	57	30	51	127	67
	7.5	18	45	24	40	100	52
	12.5	13	33	17	29	73	38
	17.5	7	16	9	15	36	19
	22.5	3	8	4	7	18	10
-22.5	2.5	17	41	22	37	91	48
	7.5	13	33	17	29	73	38
	12.5	10	25	13	22	55	29
	17.5	5	12	6	11	27	14
-27.5	2.5	12	29	15	26	64	33
	7.5	8	21	11	18	46	24

Note 1: Luminous intensity values for equivalent left and right horizontal angles are the same.
Note 2: Tabulated values of luminous intensity are rounded to the nearest whole value.

Table 2

Table 2 provides the minimum maintained luminous intensity values for the VTCSH LED Circular Signal, for the range from 12.5 degrees above to 22.5 degrees below the horizontal plane, and from 27.5 degrees left to 27.5 degrees right of the vertical plane, at 2.5 degree increments.

Minimum Maintained Luminous Intensity Values—VTCSH LED Circular Signal

Vertical Angle	Horizontal Angle	Luminous Intensity (candela)					
		200 mm (8-inch)			300 mm (12-inch)		
		Red	Yellow	Green	Red	Yellow	Green
+12.5	0.0	18	45	24	40	100	52
	2.5	17	41	22	37	91	48
	5.0	17	41	22	37	91	48
	7.5	13	33	17	29	73	38
+10.0	0.0	23	57	30	51	127	67
	2.5	23	57	30	51	127	67
	5.0	21	53	28	47	118	62
	7.5	18	45	24	40	100	52
+7.5	0.0	31	78	41	69	173	90
	2.5	31	78	41	69	173	90
	5.0	28	70	37	62	155	81
	7.5	25	62	32	55	137	71
	10.0	21	53	28	47	118	62
	12.5	18	45	24	40	100	52
+5.0	0.0	46	115	60	102	255	133
	2.5	45	111	58	99	246	128
	5.0	41	103	54	91	228	119
	7.5	36	90	47	80	200	105
	10.0	31	78	41	69	173	90
	12.5	25	62	32	55	137	71
+2.5	0.0	69	172	90	153	382	200
	2.5	68	168	88	150	373	195
	5.0	63	156	82	139	346	181
	7.5	56	139	73	124	309	162
	10.0	46	115	60	102	255	133
	12.5	38	94	49	84	209	109
	15.0	30	74	39	66	164	86
	17.5	21	53	28	47	118	62
	20.0	17	41	22	37	91	48
	22.5	12	29	15	26	64	33
0.0	0.0	106	262	138	234	582	304
	2.5	102	254	133	226	564	295
	5.0	96	238	125	212	528	276
	7.5	84	209	110	186	464	242
	10.0	71	176	92	157	391	204
	12.5	58	144	75	128	319	166
	15.0	45	111	58	99	246	128
	17.5	33	82	43	73	182	95
	20.0	25	62	32	55	137	71
	22.5	18	45	24	40	100	52

Table 2 (cont'd)

Vertical Angle	Horizontal Angle	Luminous Intensity (candela)					
		200 mm (8-inch)			300 mm (12-inch)		
		Red	Yellow	Green	Red	Yellow	Green
-2.5	0.0	165	410	215	365	910	475
	2.5	162	402	211	358	892	466
	5.0	150	373	196	332	828	432
	7.5	132	328	172	292	728	380
	10.0	112	279	146	248	619	323
	12.5	91	226	118	201	501	261
	15.0	71	176	92	157	391	204
	17.5	53	131	69	117	291	152
	20.0	38	94	49	84	209	109
	22.5	28	70	37	62	155	81
	25.0	20	49	26	44	109	57
	27.5	15	37	19	33	82	43
-5.0	0.0	157	390	204	347	865	451
	2.5	153	381	200	339	846	442
	5.0	142	353	185	314	783	409
	7.5	125	312	163	277	692	361
	10.0	107	267	140	237	592	309
	12.5	86	213	112	190	473	247
	15.0	66	164	86	146	364	190
	17.5	50	123	65	110	273	143
	20.0	36	90	47	80	200	105
	22.5	26	66	34	58	146	76
	25.0	20	49	26	44	109	57
	27.5	15	37	19	33	82	43
-7.5	0.0	130	324	170	288	719	375
	2.5	127	316	166	281	701	366
	5.0	119	295	155	263	655	342
	7.5	106	262	138	234	582	304
	10.0	89	221	116	197	491	257
	12.5	71	176	92	157	391	204
	15.0	56	139	73	124	309	162
	17.5	41	103	54	91	228	119
	20.0	30	74	39	66	164	86
	22.5	21	53	28	47	118	62
	25.0	17	41	22	37	91	48
	27.5	12	29	15	26	64	33
-10.0	0.0	89	221	116	197	491	257
	2.5	86	213	112	190	473	247
	5.0	81	201	105	179	446	233
	7.5	71	176	92	157	391	204
	10.0	59	148	77	131	328	171
	12.5	48	119	62	106	264	138
	15.0	38	94	49	84	209	109
	17.5	28	70	37	62	155	81
	20.0	20	49	26	44	109	57
	22.5	15	37	19	33	82	43
	25.0	12	29	15	26	64	33
	27.5	8	21	11	18	46	24

Table 2 (cont'd)

Vertical Angle	Horizontal Angle	Luminous Intensity (candela)					
		200 mm (8-inch)			300 mm (12-inch)		
		Red	Yellow	Green	Red	Yellow	Green
-12.5	0.0	50	123	65	110	273	143
	2.5	50	123	65	110	273	143
	5.0	46	115	60	102	255	133
	7.5	40	98	52	88	218	114
	10.0	35	86	45	77	191	100
	12.5	28	70	37	62	155	81
	15.0	21	53	28	47	118	62
	17.5	17	41	22	37	91	48
	20.0	12	29	15	26	64	33
	22.5	8	21	11	18	46	24
	25.0	7	16	9	15	36	19
	27.5	5	12	6	11	27	14
-15.0	0.0	30	74	39	66	164	86
	2.5	30	74	39	66	164	86
	5.0	28	70	37	62	155	81
	7.5	25	62	32	55	137	71
	10.0	20	49	26	44	109	57
	12.5	17	41	22	37	91	48
	15.0	13	33	17	29	73	38
	17.5	10	25	13	22	55	29
	20.0	7	16	9	15	36	19
	22.5	5	12	6	11	27	14
-17.5	0.0	23	57	30	51	127	67
	2.5	23	57	30	51	127	67
	5.0	21	53	28	47	118	62
	7.5	18	45	24	40	100	52
	10.0	17	41	22	37	91	48
	12.5	13	33	17	29	73	38
	15.0	10	25	13	22	55	29
	17.5	7	16	9	15	36	19
	20.0	5	12	6	11	27	14
	22.5	3	8	4	7	18	10
-20.0	0.0	20	49	26	44	109	57
	2.5	20	49	26	44	109	57
	5.0	18	45	24	40	100	52
	7.5	17	41	22	37	91	48
	10.0	13	33	17	29	73	38
	12.5	12	29	15	26	64	33
	15.0	8	21	11	18	46	24
	17.5	7	16	9	15	36	19
-22.5	0.0	17	41	22	37	91	48
	2.5	17	41	22	37	91	48
	5.0	15	37	19	33	82	43
	7.5	13	33	17	29	73	38
	10.0	12	29	15	26	64	33
	12.5	10	25	13	22	55	29
	15.0	7	16	9	15	36	19
	17.5	5	12	6	11	27	14

Table 2 (cont'd)

Vertical Angle	Horizontal Angle	Luminous Intensity (candela)					
		200 mm (8-inch)			300 mm (12-inch)		
		Red	Yellow	Green	Red	Yellow	Green
-25.0	0.0	15	37	19	33	82	43
	2.5	13	33	17	29	73	38
	5.0	13	33	17	29	73	38
	7.5	12	29	15	26	64	33
-27.5	0.0	12	29	15	26	64	33
	2.5	12	29	15	26	64	33
	5.0	10	25	13	22	55	29
	7.5	8	21	11	18	46	24

Note 1: Luminous intensity values for equivalent left and right horizontal angles are the same.
Note 2: Tabulated values of luminous intensity are rounded to the nearest whole value.

Figure 1

Color Regions for LED Traffic Control Signal Lights:

Figure 1 illustrates the acceptable color regions for traffic control signal lights using LED emitters as the light source.

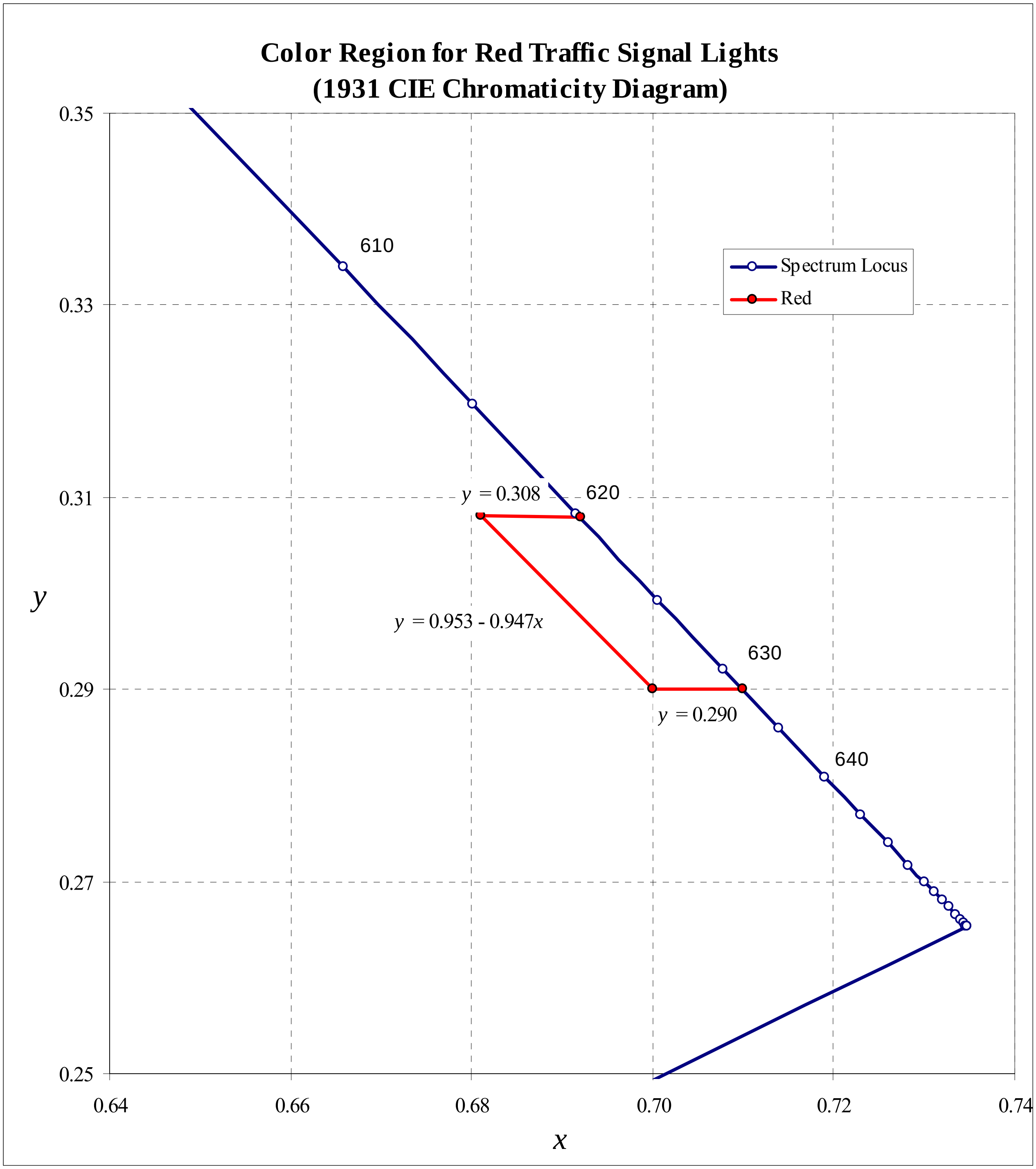

Figure 1a: Color Region for Red Traffic Control Signal Lights

Figure 1 (cont'd)

Color Regions for LED Traffic Control Signal Lights:

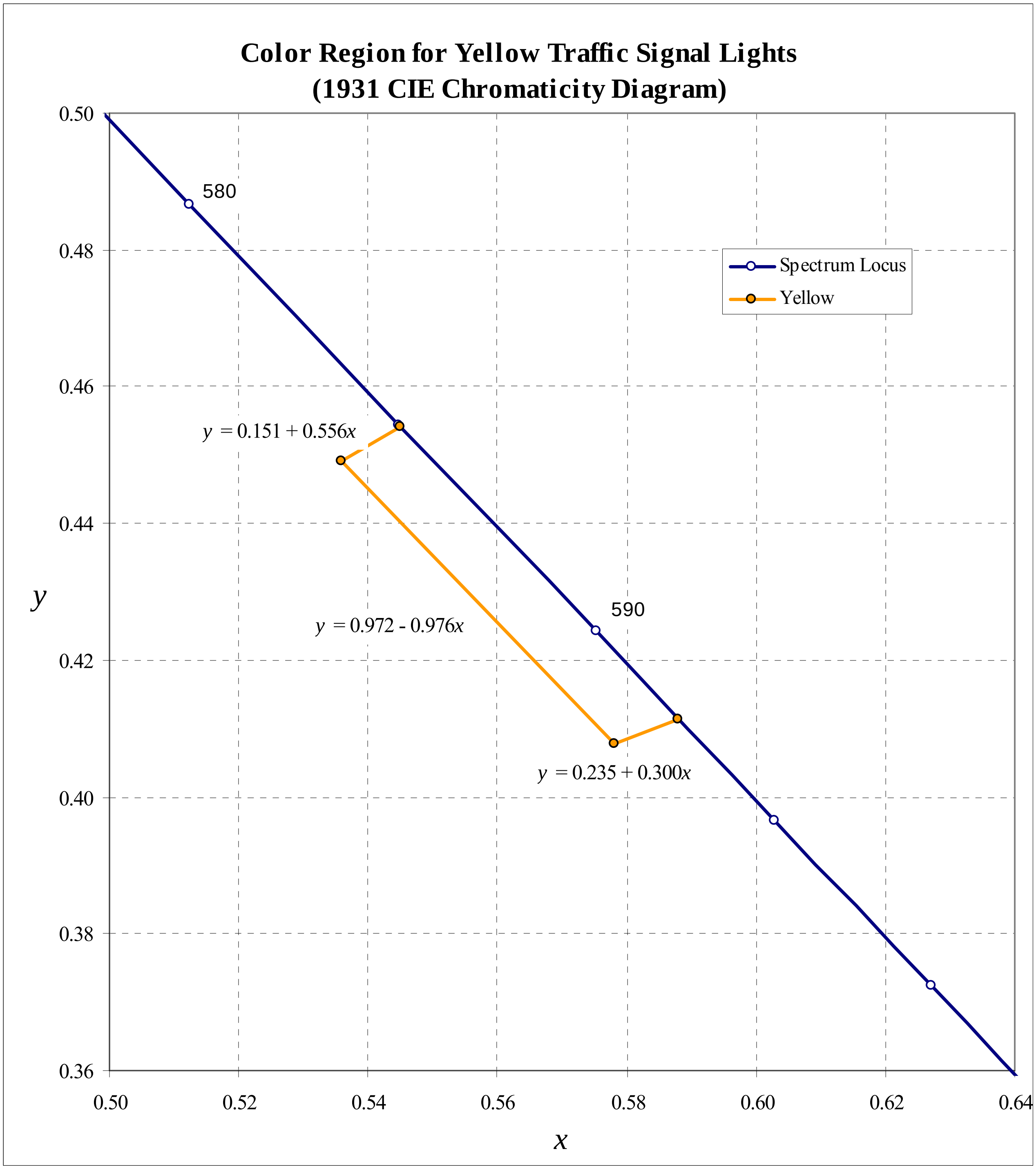

Figure 1b: Color Region for Yellow Traffic Control Signal Lights

Figure 1 (cont'd)

Color Regions for LED Traffic Control Signal Lights:

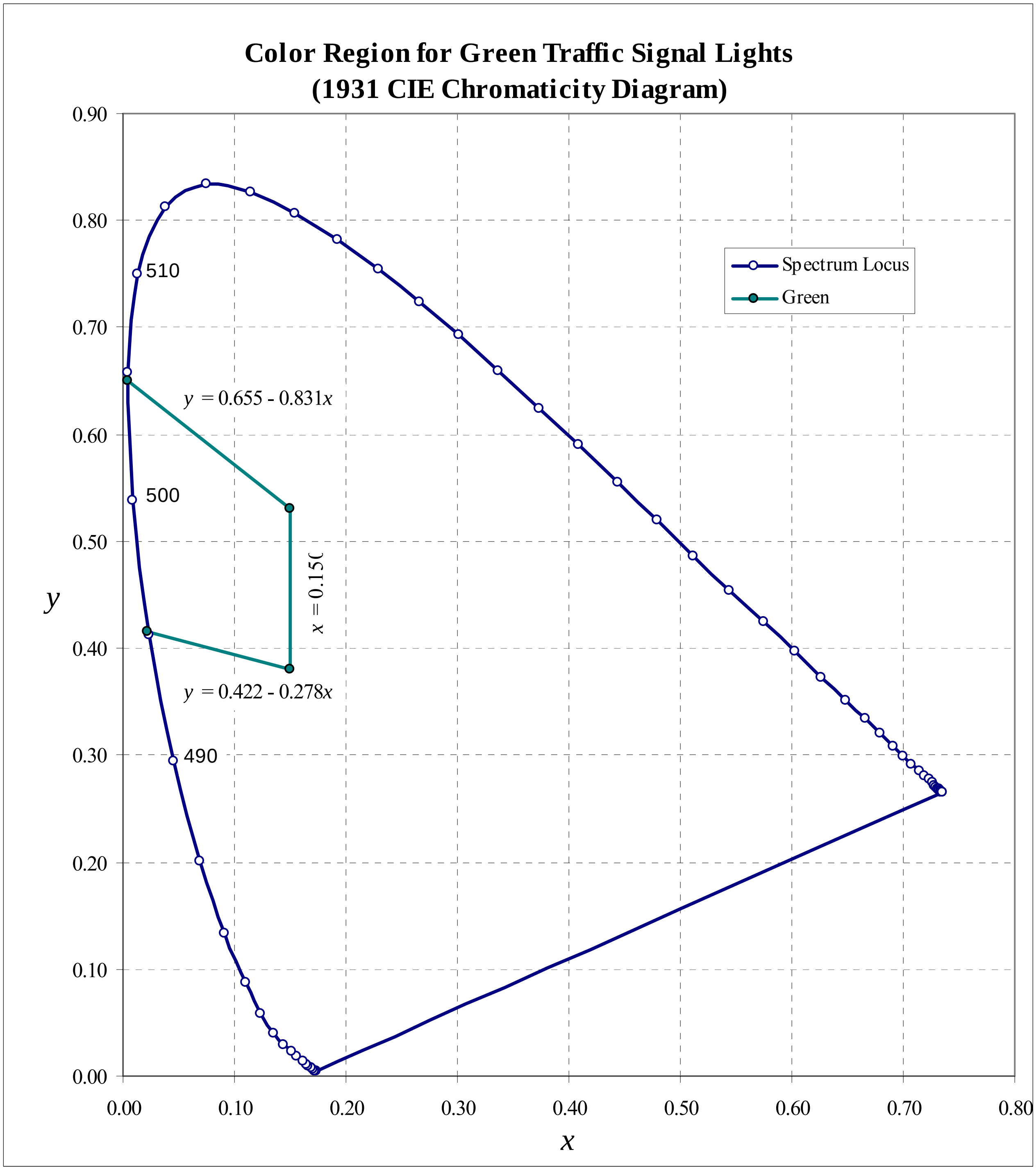

Figure 1c: Color Region for Green Traffic Control Signal Lights

Figure 2

Design Qualification Testing Flow Chart:

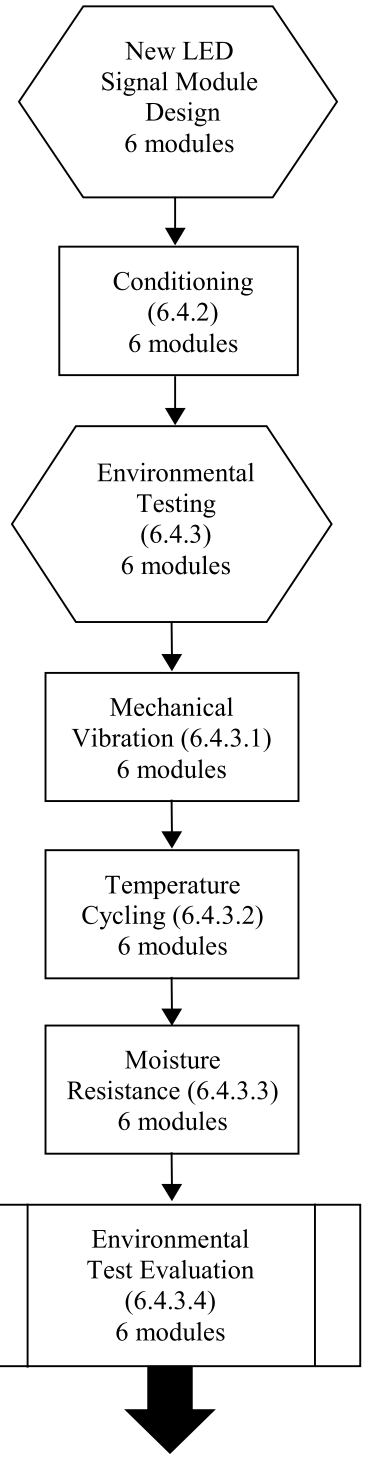

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Figure 2: Design Qualification Testing Flow Chart

Figure 2 (cont'd)

Design Qualification Testing Flow Chart:

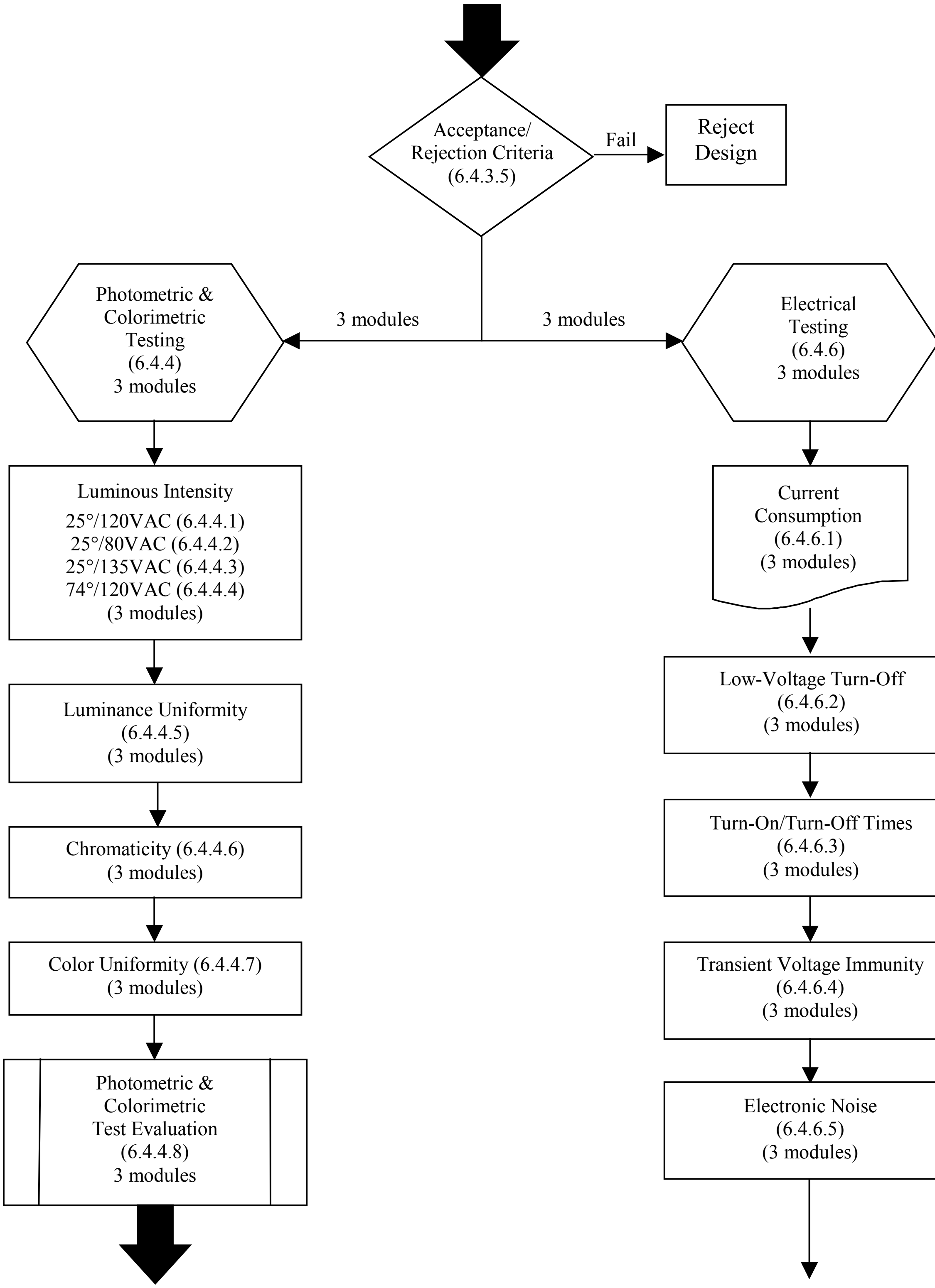

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Figure 2 (cont'd)

Design Qualification Testing Flow Chart:

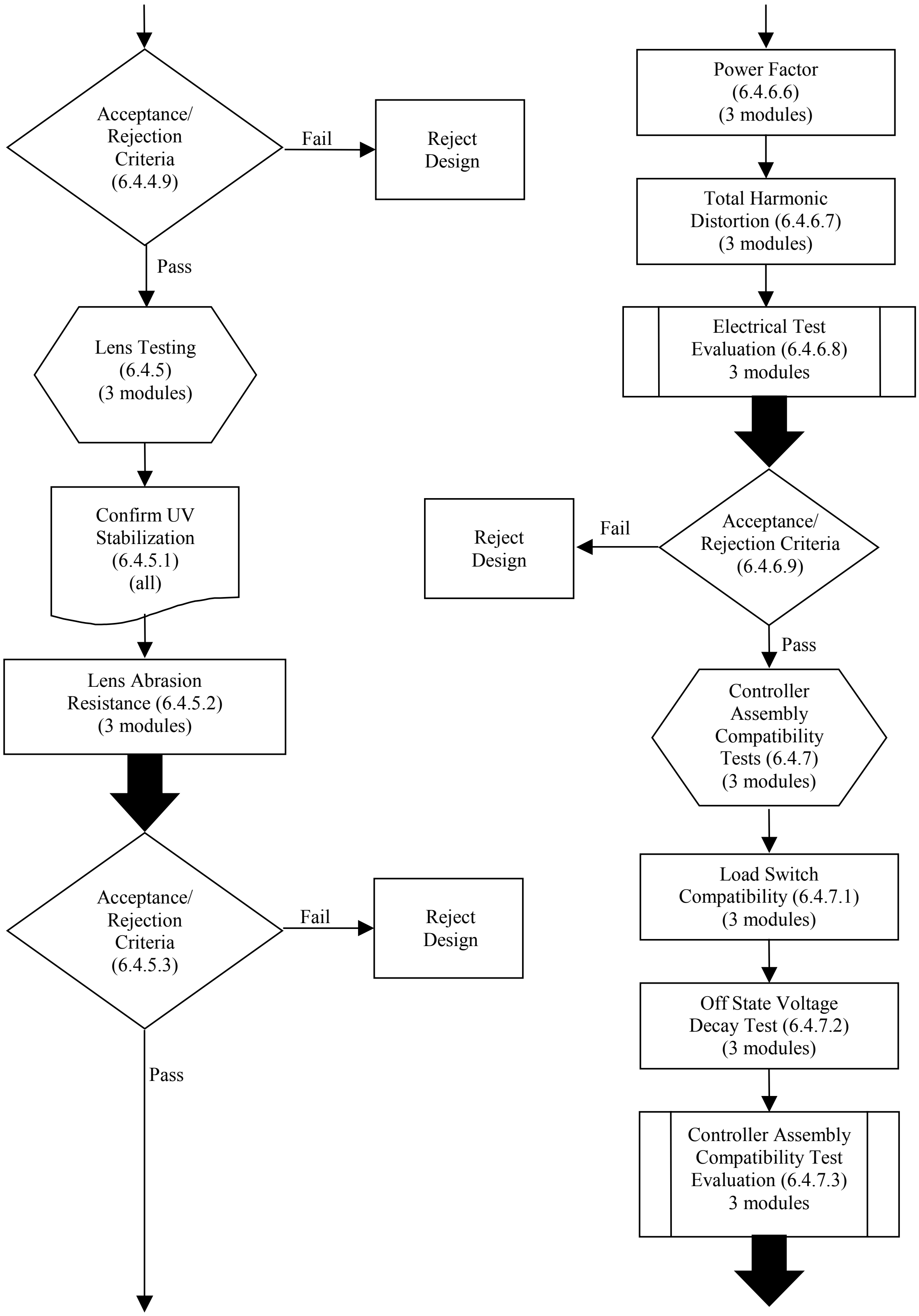

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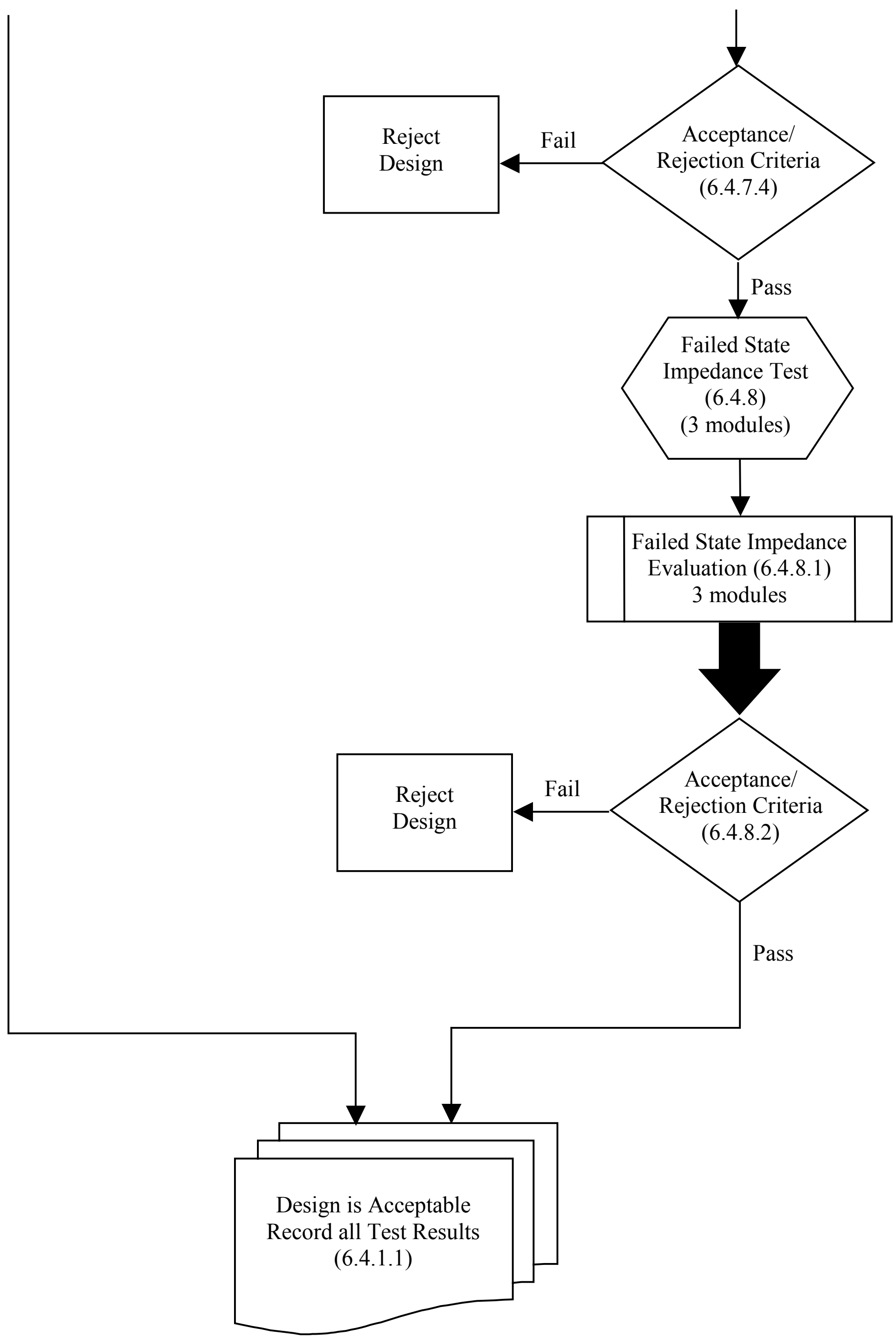
Figure 2 (cont'd)

Design Qualification Testing Flow Chart:



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Development of Luminous Intensity Requirements for VTCSH LED Circular Signal Supplement:

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Introduction to the Technical Notes

The following technical notes are added for clarification and better understanding of the testing, application, and operation of LED traffic signal modules. They are intended for the guidance of users and manufacturers.

1. Maintenance of Light Output;
2. Dimming;
3. Compatibility of LED Modules with Load Switches and Conflict Monitors;
4. Operating Temperature Range and Impact of Environmental Conditions;
5. Design Qualification Testing in an Environmental Chamber; and
6. Warranty.

This specification was developed from various research results, which provide data on the minimum human factors requirements for recognition and response/reaction to traffic signals by motorists. A bibliography has been added for those who seek a better understanding of the process followed in development of the specification, as well as the specific research and data that were used. The bibliography also includes those specifications and standards that are referenced in this document.

This specification establishes the minimum requirements for luminous intensity and emitted color of traffic signal lights, along with other physical requirements. However, traffic signal visibility involves other parameters as well. The adequacy of any given signal is an involved process, requiring engineering judgment and diligent and consistent monitoring and maintenance. Part 4 of the MUTCD contains a number of requirements and guidance on how traffic signal visibility is to be provided for.

The requirements and guidance in this specification and in the following technical notes should be regarded as minimums that do not necessarily account for all issues related to the adequacy of a given traffic signal light. It is recommended that those responsible for purchase, installation, operation and maintenance of LED traffic signals acquire additional sources of information on the factors that impact traffic signal visibility. Particular care should be taken with regards to the number and position of signals modules and the use of backplates, which are effective in increasing signal conspicuity. Other documents, listed in the bibliography, provide information regarding these issues, which will allow the user to determine the adequate steps to improve and assure signal visibility.

Technical Note #1:

Maintenance of Light Output of Signal Modules

Background.

LEDs are semiconductor devices that lose their light output gradually over time, and instant failures like incandescent lamps are rare. It is important for agencies using LED traffic signal modules to be cognizant of the light output loss of these devices in the field so that they may be replaced when the minimum light output requirements described in Section 4 of the specification are no longer met.

If there are catastrophic failures (a single LED goes dark), string failures (a number of LEDs in a circuit goes dark) or power supply failures (entire signal face goes dark), then signal maintenance personnel can visually spot the problem and replace the affected modules. However, as a module gets dimmer, it is more difficult to determine when the signal intensity falls below the required minimum levels. In addition, in some designs there are a few high brightness LEDs installed behind a Fresnel lens, wherein the individual LEDs are not visible. Failure of a single LED will make the module dimmer, but the individual failed LEDs are not distinguishable.

Some LED signal manufacturers offer a visible warning indicator option that disfigures the traffic signal in some manner (e.g. dark band across the face of the module) to indicate that the light output of the signal may be below a certain minimum level. It is important to note that technology such as this is typically based on a secondary parameter (e.g. voltage, current flow), not on a direct light output measurement of the signal. Therefore, an indicator such as this may not be fully accurate for all situations. Additionally, some jurisdictions prefer not to use an indicator that implies that a module is in place in the field that does not meet specifications.

Recommendations.

Proper utilization of LED traffic signal technology and the recommended method of maintaining the minimum light output, as specified in Section 4, require routine and systematic monitoring and maintenance activities. Such activities should include record keeping, scheduled field observations and lens cleanings.

Data on LED signals, such as manufacturer's name, model number, serial number, date of purchase, date of installation, warranty end date (if applicable) and end of useful life, should be collected and maintained to support this effort. Field observations should include some subjective and/or objective measure of appearance and/or light output. Lens cleaning intervals, depending on climate and other issues, may vary between 1 to 2 years.

A determination of “expected useful life” of the population should also be made. *Expected useful life* may be defined as the lapsed time since installation when the light output of a certain percentage of the installed base of LED traffic signal modules begin to fall below the specified minimums, that brings into question the reliability of the population in terms of light output as well as other operational characteristics. This is the lapsed time in which a jurisdiction would perform a cycled re-lamping program (replace all the LED signals that were installed at that time), similar to what is done with incandescent traffic signal lamps. The expected useful life needs to be determined by individual agencies, based on life data supplied by the LED signal manufacturer.

Almost all manufacturers can provide the purchasing agency with initial module light output values. This may be also available from, or verified by, an independent photometric laboratory. During the lens cleaning process, sample readings may be taken from some modules (or modules suspected of defects) either by removing it and sending it to a laboratory, or in situ with a portable calibrated light meter. This process is particularly important as the warranty period offered by the manufacturer comes to an end. If such data is recorded for the same modules over time (with proper adjustment for temperature or other factors), an agency can monitor the light output loss of its modules over time, and take action (e.g.: establish a group replacement or similar re-lamping approach) to minimize the potential for inadequate signals.

Note of Caution: A properly calibrated portable light meter may be used to measure the change in luminous intensity as a percentage of the initial intensity. However, portable light meters will not necessarily provide an accurate measure of the actual luminous intensity of LED traffic signal modules.

Technical Note #2:

Dimming

Discussion.

Section 5.8 of the specification provides the user the option to require dimming capability on LED signal modules in response to ambient lighting conditions. Section 5.8.2 provides for minimum luminous intensity values to be maintained when traffic signal modules are dimmed.

The technology used for dimming may be incorporated into the design of the LED traffic signal module. Where dimming is currently provided at an intersection, the existing light sensing device can be used to trigger dimming of LED modules (thus, dimming all signal modules equally).

Note of Caution: The use of devices or technology designed to dim incandescent traffic signal lamps may damage LED traffic signal modules or cause the modules to malfunction. Purchasers should inform the supplier of LED modules of their intent to use existing sensing devices and of the nature of the existing control mechanisms and hardware characteristics.

Technical Note #3:

Compatibility of LED Modules with Load Switches and Conflict Monitors

Background.

Since LED modules use very little power, some agencies have encountered incompatibility problems with existing load switches and signal conflict monitors in the field, especially if the field equipment is older. Such problems may include flickering of the LED modules, or complete blackouts. Though the occurrence is not very common, it is difficult to estimate the number of incompatible units in the field and the actual potential for such a problem. An agency may choose to replace field equipment, or specify a module that will be compatible with the existing field equipment, whichever is more economical or feasible to the agency.

Recommendation.

While the incompatibility problem with conflict monitors may be avoided by conducting the test specified in section 6.4.7 of the specification, load switches operating at the reduced levels of LED module load current may still fail to operate correctly. If the agency chooses to specify a compatible unit, the following verbiage may be included in the specifications.

> "A sample of LED signal modules shall be tested for compatibility with existing load switches. Each signal module shall be connected to an AC voltage supply between the values of 80Vac and 135Vac, and the line current shall be measured under conditions where the LED signal module has the minimum power consumption. Within each half line cycle, the load current shall temporarily exceed 150mA to ensure proper triggering of the lead switch. The load current shall, after reaching 150mA, remain continuously above 100mA for a time span long enough to ensure that the rms load current during this time span is at least 50% of the total rms load current."

It may be wrongly concluded that this requirement may increase the wattage of the LED unit significantly. Please note that the current needed for proper triggering and holding of load switch triacs will not require a continuous high current level by a modification in the current profile. This uneven flow may increase the total harmonic distortion (THD) in the current drawn. This specification will allow for design of low wattage units, if the maximum THD requirement for such low wattage units is set at 0.4, unlike high power units, where the maximum should be 0.2 (see section 5.5.2 of the specification).

Technical Note #4:

Operating Temperature Range and Impact of Environmental Conditions

Background.

An operating temperature range, based on standards typical in the electronics industry, has been included in the specification. Since the light output of LEDs diminishes as the ambient temperature increases, internal temperatures substantially in excess of the 74°C (165°F) upper limit included in the specification could result in unacceptable LED module performance. A study undertaken by ITE as a part of the specification development process indicates that the internal temperature within a traffic signal section is likely to exceed the upper limit of the operating range for certain combinations of signal material, signal color, solar load, and ambient temperature.

Established study boundaries included the following:

- Both 200mm (8-inch) and 300mm (12-inch) heads were tested.
- Traffic signal head types included aluminum and polycarbonate, both yellow and black in color.
- Ambient temperatures of 32°C (90°F) to 49°C (120°F) were evaluated.
- Solar loads of 900, 960, 985, and 1,000 watts/m^2 (representative of those experienced at latitudes of 20°, 30°, 40°, and 50°, respectively) were evaluated.

In addition to the basic signal head, color, and size combination previously described, one 200mm (8-inch) and one 300mm (12-inch) head were equipped with vents to permit convection cooling within the signal head cavities. Vents were installed in the back of the red sections and at the bottom of the green sections. The vents were 50mm (2-inches) and 75mm (3-inches) in diameter for the 200mm (8-inch) and 300mm (12-inch) heads, respectively.

Conclusions.

The underlying question, which prompted ITE to initiate testing, was "Are there environmental and/or geographic conditions that present operating temperatures and conditions beyond what is reflected in the specification that would cause any additional reduction in the luminous intensity of an LED module?"

The following test conditions produced temperatures internal to the red indication housing that exceeded the upper limit of the operating temperature range defined in the specification:

- Solar loads equivalent to those typically encountered at 40° or less latitude with ambient temperatures of 43°C (110°F) or higher within 200mm (8-inch) black plastic heads.
- Solar loads equivalent to those typically encountered at 30° or less latitude with ambient temperatures of 49°C (120°F) or higher within 300mm (12-inch) black plastic heads.

None of the other color/material combinations resulted in internal temperatures in excess of 73°C (164°F) at any solar load/ambient temperature combination. Venting of the signal heads was found to be an effective means of reducing temperatures within the heads to a point within the operating temperature range reflected in the specification.

Recommendation.

Agencies that use 200mm (8-inch) black plastic signal housings **and** are located at or below 40°N latitude **and** regularly experience ambient air temperatures in excess of 43°C (110°F) should approach the use of LED modules with an upper limit operating temperature of 74°C (165°F) with caution. The use of 300mm (12-inch) modules in black plastic housings should also be approached with caution but the critical range is limited to 30°N latitude or below **and** an ambient air temperature of 49°C (120°F) or higher.

Modification of the operating temperature range to provide an upper limit of 81°C (178°F) would result in the required light output being maintained under all of the conditions tested. The use of vents or other means of controlling the internal temperature, however, may be an appropriate alternative to modifying the operating temperature range.

Technical Note #5:

Design Qualification Testing in an Environmental Chamber

Introduction.

This technical note addresses the issues implicit in Section 6.4 Design Qualification Testing. Specifically, this note relates to the testing method employed to ascertain compliance with maintenance of the specified luminous intensity for LED modules at elevated temperatures (6.4.4.4). The operating temperature for this test has been established to be 74°C (165°F) for the air at the rear of the LED module, and 49°C (120°F) for the air in front of the module.

A method to establish the "dual environment" for design qualification testing and/or subsequent validation of production samples is outlined below.

Test Hardware Description

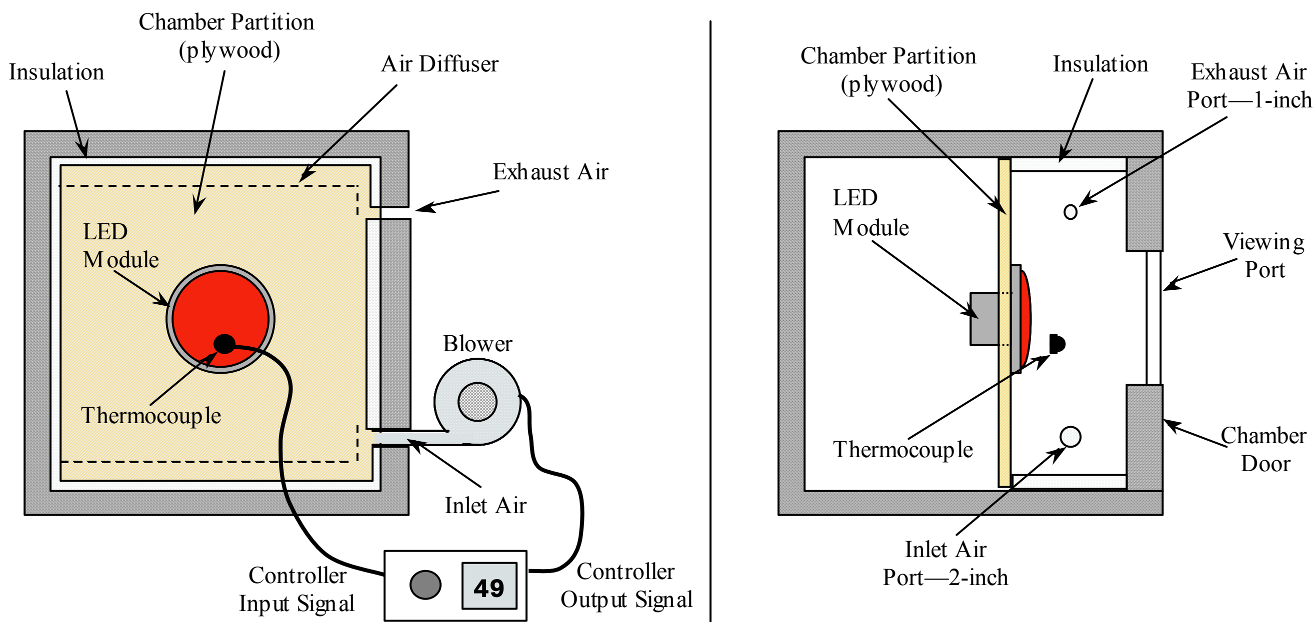
The testing hardware involves adaptation of existing environmental testing chambers, which are normally configured to provide an adjustable hot or cold environment and have provisions for visual or instrumental inspection.

A plywood chamber divider, with provision for mounting one or more LED signal modules, may be installed in the chamber, with adequate edge insulation to partially isolate the front partition of the test chamber from the rear section. The front chamber section can be maintained at the required 49°C (120°F) while the rear portion is held at 74°C (165°F) by applying the correct amount of insulation to the chamber divider wall. This passive method, while certainly very low in cost, requires a fair amount of experimentation. In light of currently available, moderately priced temperature controllers, an active system is preferable.

Figure TN5-1 illustrates how to achieve a dual temperature environment with an existing commercial environmental test chamber. A small centrifugal blower is used to induce ambient air, nominally 25°C (77°F) into the front portion of the chamber. This ambient air is used to cool the heated air that collects in the forward chamber due to heat transfer through the divider wall. A diffuser allows for proper air mixing, and an exhaust port permits heated air to escape from the front chamber. An auto-tuning P.I.D. (proportional, integral, derivative) single-loop controller is used to maintain the front chamber at an air temperature of 49°C (120°F). A type K thermocouple, mounted approximately 20 mm from the front lens of the LED module may be used as the sensing element. The temperature controller operates the small blower in an "ON-OFF time proportioning mode," so that an air temperature of 49°C (120°F) is maintained in the front chamber, while a temperature of 74°C (165°F) is maintained in the rear chamber.

Active control of the dual chamber is simplified by the use of a microprocessor-based, auto-tuning controller that allows for 2°C (3.6°F) set-point maintenance over a wide range of operating variables. The auto-tuning controller will "learn" the optimal control variables to maintaining the desired chamber temperatures in less than two hours of operation. These settings are then stored in memory and are automatically applied to all subsequent tests that require similar testing environments.

Figure TN5-1: Diagram of Proposed Environmental Test Chamber



Front View of Modified Chamber
(door not shown)

Side View of Modified Chamber
(controller, blower & wiring not shown)

Components:

1. Chamber partition: ¾ inch plywood, cut to fit chamber interior dimensions;
2. Insulation: 1 inch rigid Styrofoam insulation board;
3. Blower: 100 cfm (nominal) centrifugal blower, 2 inch discharge port; and
4. Temperature controller: Auto-tuning PID single-loop controller with ASTM Type K thermocouple.

Technical Note #6:

Warranty

Discussion.

A warranty is usually defined as that period of time within which a manufacturer must replace or repair an installed LED module that, under normal operating conditions, has failed or shown some deficiencies (according to the purchasing agency's adopted specification). Required minimum warranties are not part of these specifications because it is a market-driven factor. Carefully crafted market-based warranty requirements can be an effective means to help assure that the requirements of the specifications are met, even after the signal modules have been installed and are operational. However, warranty requirements in themselves are not effective unless the purchaser is prepared to record, track, evaluate, inspect and measure the performance of the LED modules in a routine and systematic fashion. It is important to note that to enforce the minimum requirements of intensity and emitted color, actual measurements may be necessary, which can involve expensive equipment and time consuming and tedious processes (see Technical Note #1).

Recommendation.

Although the specifications do not require a minimum warranty, Sections 3.3.1, 3.3.4, 4.1.1, 6.4.1.1 and 6.4.6.1 all refer to a 60-month performance requirement for parts and light output. Hence, it is typically reasonable to set a warranty period that the LED signal module will perform to the requirements of this specification for a minimum of 60 months. Longer minimum warranty time periods may be available, depending on a variety of factors (e.g.: climate, market conditions, etc.). Thus, it is recommended that the purchaser survey the market for available warranties prior to establishing contractual requirements. Typically it is not feasible to set requirements that are too restrictive or are beyond what the market is offering. It is also up to the user agency to determine what the remedy associated with the warranty is: e.g.: full replacement with labor, materials only, prorated cost reimbursement, etc.

It is also important to note that in some instances the actual useful life of an LED module (i.e.: when it still meets minimum intensity and emitted color requirements) may be longer than the warranty period. Purchasers should discuss data on useful life of LED modules with the manufacturers. The difference in designing a module to meet a specified service life, and warranting that all modules will meet that service life may result in a significant price difference. Therefore, agencies should closely evaluate the cost/benefit of extended warranties as opposed to a standard, market-based warranty.