Roadway Lighting Design

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XIII. Designing the Lighting System

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I. Introduction

The general purpose of roadway lighting is to provide improved visibility for the various users of the roadways and associated facilities.

"Users" refer to vehicle operators (automobiles, trucks, buses, motorcycles, bicycles), pedestrians and other citizens such as merchants and shoppers.

"Associated Facilities" refer to physical features along the roadway (barriers, bridge piers, ditches, curbs, channelization, etc.).

Roadway lighting on local streets provides pedestrian visibility as well as driver visibility. Lighting quality increases the comfort level and safety of the motorist. Lighting can be expected to reduce night crashes by approximately 30 percent.

A. Objectives of Roadway Lighting

- To supplement vehicle headlights, extending the visibility range beyond their limits both laterally and longitudinally.
- To improve the visibility of roadway features and objects on or near the roadway.
- To delineate the roadway ahead and improve visibility of the surroundings.
- To reduce the apprehension of those using the roadway.

B. Visibility Requirements

Vision – The eyes are the primary source of information. As light decreases, vision and the detection of information are severally impaired or nonexistent. As light increases, vision and the detection of information are improved.

Contrast is the difference in brightness between the object and background. The ability to discern objects increases as the contrast level between the two increases. Drivers normally see objects in silhouette – a dark area against a bright background. This bright background can cause a glare resulting in a reduction in the contrast level thereby partially or totally obscuring the details to be seen.

II. Analyzing Lighting Needs

The warrants for roadway lighting are located in AASHTO's "An Informational Guide for Roadway Lighting". The manual contains a basic guide for highway lighting and contains design guidelines and warranting criteria.

A lighting justification analysis was created due to the energy crisis of the 1970's and based on recommendations of a research project; a lighting justification program was developed. It is used to calculate the cost benefit analysis of lighting. The FDOT Office of Traffic Operations in Tallahassee may be contacted for a copy of the program.

III. Lighting Equipment

A. Light Sources

There are three general types of light sources: LED, filament and arc-discharge.

Light Source	Type	Lumens	Life (hrs)
LED	LED	2-90	50,000
Filament Lamp	Incandescent	10-15	12,000
Discharge Lamp	Fluorescent	60-70	7,500-24,000
	Mercury Vapor	50-65	24,000
	Metal Halide	90-110	10,000-20,000
	High Pressure Sodium	125-140	24,000
	Low Pressure Sodium	180	18,000

LED (Light-Emitting Diode)

An LED roadway light is an integrated light that uses light emitting diodes (LED) as its light source. These are considered integrated because the luminaire and fixture are not separate parts. Most LED roadway lights have a lens on the LED panel, which is designed to cast its light in a rectangular pattern aiming the majority of the light to the street side. The primary appeal of LED roadway lighting is energy efficiency compared to conventional roadway lighting fixture technologies. An LED fixture uses considerable less electricity than the traditional light fixtures. In addition, an LED fixture will have a longer life than the traditional light fixtures. This results in a reduction in maintenance cost. A disadvantage of LED lighting is increased glare.

Incandescent Lamp

The incandescent lamp has a filament that is an electrical resistance wire enclosed in a gas filled bulb. Current passing through the filament heating the filament to incandescence produces light. The gases are inert, usually nitrogen or krypton, which reduce evaporation of the filament and act as a thermal barrier.

Discharge Lamp

The discharge lamp produces light by exciting gases or metal vapors in a lamp or tube. Electrical potential is applied to electrodes. Gas is ionized and current flows between the electrodes. The lamps have a negative resistance and must have a ballast to maintain proper current level. The ballast regulates input power for the lamp.

Fluorescent Lamp - The fluorescent lamp produces light by a fluorescent coating on the inside of the tube which is activated by an ultraviolet energy generated by an arc.

Mercury Vapor - The mercury vapor lamp consists of an arc tube inside the outer bulb containing mercury vapor and electrodes. Light is produced from ionization of mercury vapor. Lamps may be clear or coated with phosphors to improve color rendition.

Metal Halide - Metal halide light is produced by a combination of metallic vapors. The lamp has excellent color rendition, but has a short lamp life.

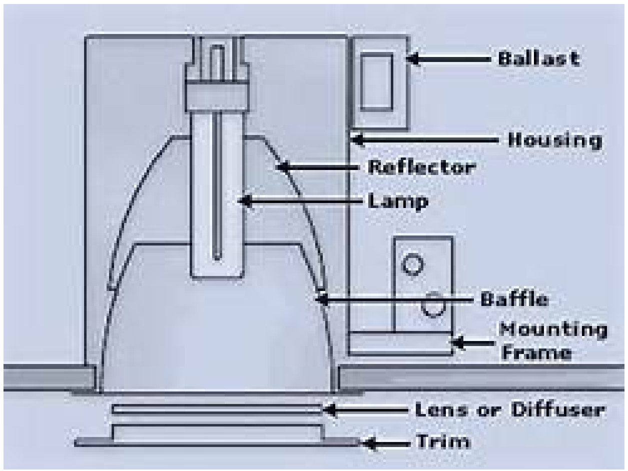
High Pressure Sodium - The high pressure sodium lamp produces light from sodium vapor. The arc tube is normally filled with sodium, mercury and xenon. Xenon is used for starting the light and mercury for coloring. This lamp has no starting electrode and produces a high voltage pulse of 2,500 to 4,000 volts.

Low Pressure Sodium - The low pressure sodium lamp is very efficient. However, it is monochromatic (single color only). It has a large physical size and the light is hard to control. It also has a lower lamp life.

B. Luminaries

The luminaire components consist of a housing of the ballast and optical assembly. The optical assembly components consist of the lamp, reflector and refractor. The lamp produces the light output for the luminaire. The reflector is mounted above the lamp inside the optical assembly. It reflects or redirects the light. The refractor is mounted below the lamp and in some luminaries encloses the lamp cavity. The refractor is made of a transparent, clear material, glass or a strong plastic material. It has a large number of prisms and is enclosed or open at the bottom.

The following illustration shows the components of a typical luminaire.



C. Luminaire Supports

Luminaire supports generally have frangible/breakaway bases. The breakaway criteria are covered in the AASHTO Specifications. The term “breakaway support” refers to all types of sign, luminaire and traffic signal supports that are design to yield when hit by a vehicle. The release mechanism may be a slip plane, plastic hinges, fracture elements, or a combination of these. Frangible/breakaway bases are safer in vehicular collisions since the light base will yield in the collision.

The standard pole is made of aluminum. However, in some locations they may be concrete or fiberglass. Joint use poles may combine the luminaire with signals or utilities on wood, concrete, or steel poles. All conventional height poles shall be breakaway unless bridge or barrier wall mounted. High mast poles are made of steel or concrete. These structures must be installed outside of the clear zone as they are not frangible/breakaway.

FDOT has developed an aluminum light pole standard for Conventional Lighting foundations. The standard provides details for 40, 45 and 50-foot luminaire mounting heights on poles mounted either at grade or on fills up to 25 feet in height, all of which accommodate fixture arm lengths of 8, 10, 12 and 15 feet. Standard Aluminum Light Poles have been designed for 110, 130, and 150 mph design wind speeds. High mast lighting (80 feet or greater) requires a foundation design in the plans.

D. Bracket Arm Types

Bracket arm types may consist of single member, truss, or davit. The length and rise may vary. The length is determined in the design of the lighting system and is measured to the center of the luminaire. The rise is the difference in elevation between the attachment at the pole and connection to the luminaire. The contractor usually calculates the rise because it depends on the length of the pole and mounting height required.

Single Member
Bracket Arm

Truss Bracket Arm

Davit Bracket Arm

IV. Conventional Lighting

Conventional lighting consists of any number of mounting heights depending upon the desired lighting level. The standard FDOT mounting heights are 40, 45, and 50 feet. There is one luminaire per pole for conventional mountings. There can be two luminaries per pole if it is median mounted. The following table outlines the FDOT requirements for illumination levels and uniformity ratios for conventional lighting.

Table 7.3.1 Conventional Lighting – Roadways (FDOT PPM, Chapter 7)

Roadway Classifications	Illumination Level Average Initial Horizontal Foot Candle (H.F.C.)	Uniformity Ratios	
		Avg./Min.	Max./Min.
Interstate, Expressway, Freeway & Major Arterials	1.5	4:1 or less	10:1 or less
All Other Roadways	1.0	4:1 or less	10:1 or less
* Pedestrian Ways and Bicycle Lanes	2.5	4:1 or less	10:1 or less

V. Highmast Lighting

High mast lighting consists of a mounting height of 80 feet or greater. The standard mounting height is 120 feet. There are several luminaries per pole. The number of luminaries depends on the light level required. The maximum number of luminaries per pole is 12 highmast or 16 flood. The luminaries are attached to a ring by cables and to a winch inside the pole base. The ring and luminaries lower to the ground by the winch for maintenance. Either a heavy duty drill motor attaches to the pole to operate the winch or a previously installed electric motor lowers the ring. The following table outlines the FDOT requirements for illumination levels and uniformity ratios for high mast lighting.

Table 7.3.2 Highmast Lighting – Roadways (FDOT PPM, Volume 1, Chapter 7)

Roadway Classifications	Illumination Level Average Initial (H.F.C.)	Uniformity Ratios	
		Avg./Min.	Max./Min.
Interstate, Expressway, Freeway, & Major Arterials	0.8 to 1.0	3:1 or less	10:1 or less
All Other Roadways	0.8 to 1.0	3:1 or less	10:1 or less

The following illustrations shows high mast lighting at an interchange.

The following illustration shows a highmast light being lowered for light maintenance.

VI. Sign Lighting

Overhead sign structures require overhead sign lighting so the messages are visible during the day and night. The following table outlines the FDOT requirements for illumination levels and uniformity ratios for sign lighting.

Table 7.3.3 Sign Lighting (FDOT PPM, Volume 1, Chapter 7)

Ambient Luminance	Illumination Level Average Initial (H.F.C.)	Uniformity Ratios
		Max./Min.
Low	15-20	6:1
Medium & High	25-35	6:1

In recent years, sign manufacturers have developed a special sheeting on the sign that uses vehicle headlights to illuminate the sign. The cost of these signs is greater than the cost of conventional signs. However, the use of this type of sheeting reduces the cost of sign lighting and the associated conduit and pull boxes.

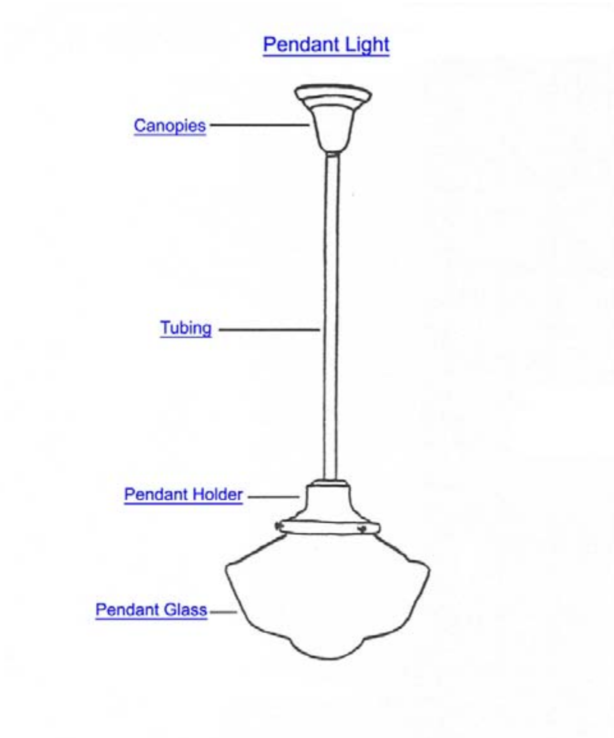
VII. Underdeck Lighting

Many of the major interchanges today have numerous wide overpasses. In these locations, lighting is required for the roadways underneath the overpasses for both day and night visibility. Underdeck lighting is accomplished by mounting either pier cap or pendant hung fixtures under the bridge structure. Pier cap luminaries should be installed when bridge piers are located less that 15 feet from edge of travel lane. Pendant hung luminaries shall be mounted to the bottom of the bridge deck and should be suspended where 50% of the lamp is below the bridge beam. Under no circumstances shall any luminaire or conduit be allowed to attach onto the bridge girders. The light levels for underdeck lighting shall be equal to the adjacent roadway lighting. The following table outlines the FDOT requirements for the light source and mounting location for underdeck lighting.

Table 7.3.4 Underdeck Lighting – Roadways (FDOT PPM Volume 1, Chapter 7)

Luminaire Type	Light Source (High Pressure Sodium)	Mounting Location
Pier Cap	150 watt to 250 watt HPS	Pier or Pier Cap
Pendant Hung	150 watt to 250 watt HPS	Bridge Deck

The following illustration shows a commonly used pendant light for underdeck lighting.



VIII. Mounting Height Restrictions

FDOT has established a minimum mounting height for high pressure sodium (HPS) luminaires of various wattages. The following table shows the minimum mounting heights per luminaire wattage.

Table 7.3.6 Mounting Height Restrictions (FDOT PPM Volume 1, Chapter 7)

Luminaire Wattage	Light Source	Mounting Height (Min.) (Feet)
150	High Pressure Sodium (HPS)	25
200	High Pressure Sodium (HPS)	30
250	High Pressure Sodium (HPS)	30
400	High Pressure Sodium (HPS)	40
750	High Pressure Sodium (HPS)	50
1000	High Pressure Sodium (HPS)	80

IX. Lighting Project Coordination

Coordination with other offices and other agencies is a very important aspect of project design. It is important that the lighting designer coordinates with roadway design, utilities, drainage, and structures.

- The roadway designer provides the base sheets and cross sections for the lighting Design to be used in the coordination.
- The utilities engineer provides the coordination between the lighting designer and the utilities involved in the project. The utilities engineer can also identify potential conflicts with overhead and underground utilities.
- The drainage designer should check the locations of highmast poles to determine if high water level is a problem. Highmast poles are often located in the center of interchange loops that may be the same areas used as drainage retention areas.
- The structural engineer should be contacted early in the design phase to allow adequate time for coordination. While conventional height pole foundations are covered in the FDOT Design Standards and FDOT Standard Specifications, highmast poles require a foundation design. In addition, soil borings are required for this design.

X. Maintenance of Existing Lighting During Construction

The maintenance of existing lighting shall be the responsibility of the contractor only if the lighting is affected by the construction. The contractor should not be expected to replace lamps and pole knockdowns or to repair wiring if these problems are not caused by the construction work. The plans should specify the scope of the contractor's responsibility for the maintenance of existing lighting.

XI. Voltage Drop Criteria

When determining conductor sizes for lighting circuits, the maximum allowable voltage drop from the service point on any one circuit is 7%.

XII. Grounding

The grounding requirements for lighting systems shall be as follows:

- Install 20’ of ground rod at each conventional height light pole and at each pull box.
- Install 40’ of ground rod at each electrical service point.
- At each highmast pole, install an array of 6 ground rods 20’ in length, as shown in the Design Standards, Index 17502.

XIII. Designing the Lighting System

A. Design Concepts

There are two concepts or techniques for the design of highway lighting allowed by the AASHTO guide for lighting.

The *Illumination Concept* is the measure of light striking a surface. Illumination is the design method adopted by the FDOT and most agencies in the United States.

The *Luminance Concept* (brightness) is the measure of light reflected from a surface. Luminance requires a more complex design process and knowledge of the reflective characteristics of the pavement surface used. These reflective characteristics change as the pavement ages and with variations in weather conditions.

There are numerous off-the-shelf computer programs to assist the engineer with lighting design. These programs use the information from the proposed luminaire along with the layout input from the engineer to determine if the fixture layout meets criteria.

B. Design Criteria

The designer responsible for a highway lighting project should be aware that the design must comply with various standards. The design criteria for highway lighting are in the FDOT Roadway Plans Preparation Manual, Volume 1, Chapter 7, FDOT Standard Specifications, FDOT Design Standards, AASHTO Roadway Lighting Design Guide and AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, and FDOT Structures Manual.

C. Lighting Terminology

It is important in the design of a lighting system that all of the appropriate terminology is understood to ensure the proper design.

Arm length is the distance from the support to the middle of the luminaire.

Coefficient of utilization is the percent of luminaire output. It is the amount of light that falls on a selected area of roadway.

House side is the side of the luminaire casting light away from the roadway.

Mounting height is the vertical distance from the roadway the light source.

Overhang is the distance between the edge of pavement to the center of the luminaire.

Pole setback is the horizontal distance from the edge of the travel lane to the pole.

Nadir is that point of the celestial sphere directly opposite to the zenith and directly below the observer. It is the lowest point.

Roadway width is the width of the roadway used in the lighting calculations for the luminaire to light.

Street side is the side of the luminaire casting light towards the roadway.

Zenith is the point in the sky directly overhead; that point of the celestial sphere directly opposite to the nadir. It is the highest point.

D. Glare

Glare is an unusual sensation caused by excessive and uncontrolled brightness. It can be disabling or simply uncomfortable. Disability glare is the reduction in visibility caused by overly bright light sources.

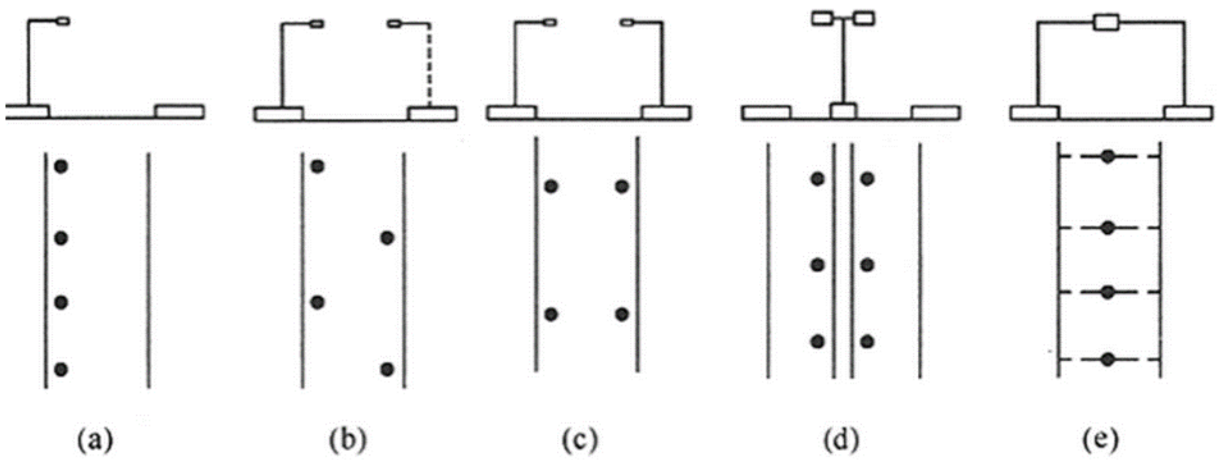
It is important that the lighting designer keep glare in mind in the design process. A design with fewer light fixtures at a higher wattage may result in the required luminance. However, the higher wattage may result in a situation with glare. Therefore, a design with more light fixtures at a lower wattage would be preferable because it would reduce the glare.

The illustration below shows a street with disability glare caused by using fewer light fixtures with higher wattages.

The illustration below shows roadway lighting without glare with the use of more fixtures with lower wattages.

E. Spacing Arrangements

Spacing arrangements consist of one side, staggered, opposite, median mounted and overhead. The lighting designer determines the spacing arrangement. The most common spacing arrangement is staggered. Some spacing arrangements may not provide proper light levels. For example, on a divided roadway with a median barrier, consider a median mounting. An illustration of the varying spacing arrangements is shown below.



(a) One Side Arrangement
(b) Staggered Arrangement
(c) Opposite Arrangement
(d) Median Arrangement
(e) Overhead Arrangement

One side arrangement is generally used on minor streets with two lanes. This is because if it was used on a wide street, there would be areas of the roadway that were darker than others. The uniformity ratios would not be acceptable.

Staggered and opposite arrangements are generally used on multi-lane facilities. This is because they provide a good distribution of light resulting in acceptable uniformity ratios.

Median arrangements are generally used on multi-lane facilities that have limited right-of-way on the outside of the roadway. By placing the lights in the median, good uniformity ratios can be obtained in limited right-of-way conditions.

Overhead arrangements are rarely used. This is because a structural system has to be designed to hold the light fixtures. The other types of arrangements have the structural supports already designed by the light manufacturer. The overhead arrangement would result in higher design and construction costs.

F. IES Light Distributions

IES light distributions are based on vertical light distribution, lateral light distribution, and control of light distribution above maximum candlepower.

Vertical Light Distribution

Short distribution – The maximum candlepower beam strikes the roadway surface between 1.0 and 2.25 mounting heights from the luminaire. This type of distribution should be used in areas where vertical light distribution is an issue such as near airports.

Medium distribution – The maximum candlepower beam strikes the roadway surface at some point between 2.25 and 3.75 mounting heights from the luminaire.

Long distribution – The maximum candlepower beam strikes the roadway surface at some point between 3.75 and 6.0 mounting heights from the luminaire. This type of distribution should not be used in areas where vertical light distribution is a concern such as near airports.

G. Types of Cutoffs

Control above maximum candlepower affects the glare from a luminaire. The following are the types of luminaries that are available for use.

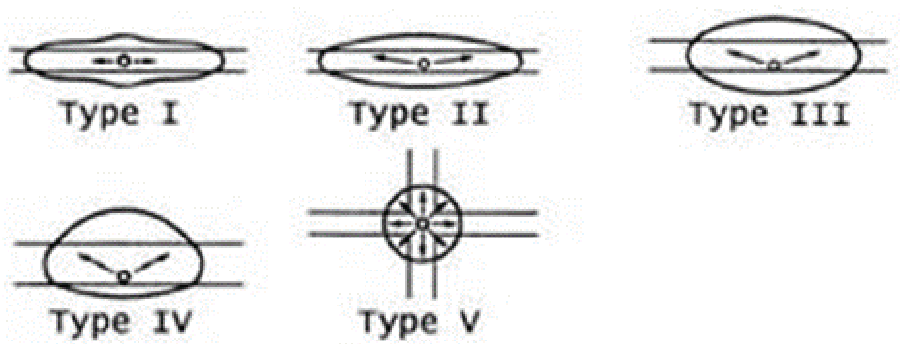
Full Cutoff - When the candlepower per 1,000 bare lamp lumens does not exceed 25 at an angle of 90 degrees above nadir; and 100 at an angle of 80 degrees above nadir. This type of luminaire would be used in an interstate corridor passing through a neighborhood because it would control the spill over light and reduce glare.

Semi-cutoff – When the candlepower per 1,000 bare lamp lumens does not exceed 50 at an angle of 90 degrees above nadir; and 200 at an angle of 80 degrees above nadir.

Non-cutoff – When there is no candlepower limitation in the zone above maximum candlepower. This luminaire would be used in a high mast condition where spill over light is not a concern such as undeveloped interchanges.

H. Types of Distribution

There are five different lateral distribution patterns to choose from when designing a lighting layout. They consist of Types I, II, III, IV and V. An illustration of the different distribution patterns is shown below.



- Type I is considered a full cutoff fixture. It is the most restrictive pattern of lighting. It concentrates the majority of the light on the roadway. There is minimal spill over light to the house side of the luminaire. This pattern of lighting is ideal for roadways within residential areas.

- Type II is considered a cutoff fixture. It is a restrictive pattern of lighting. It is slightly less restrictive than Type I. It also concentrates the majority of the light on the roadway. There is minimal spill over light to the house side of the luminaire. This pattern of lighting is ideal for roadways within residential areas.

- Type III is considered a semi-cutoff fixture. It is a less restrictive pattern of lighting than Type II. However, Type III provides light for a wider section of roadway.

- Type IV is considered a semi-cutoff fixture. It is a less restrictive pattern of lighting than Type III. However, Type IV provides light for a wider section of roadway.

- Type V is considered a non-cutoff fixture. It has a high mast lighting pattern. The light is equally distributed in a circle surrounding the luminaries. This pattern of lighting is not suitable for residential areas.

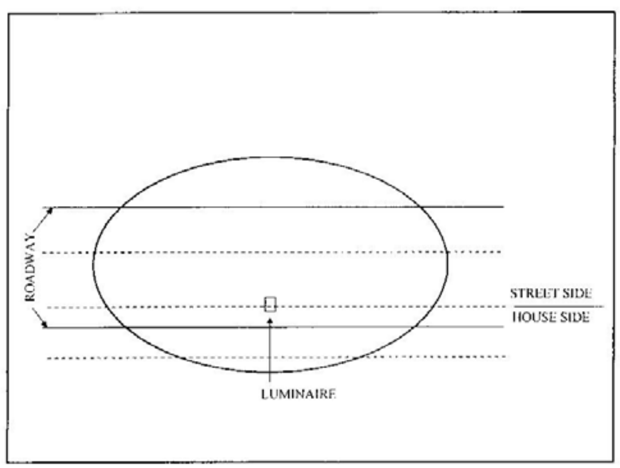
Depending on the lighting design, the luminaire can be set in the following methods:

- On the Roadway Edge
- Offset
- Overhang

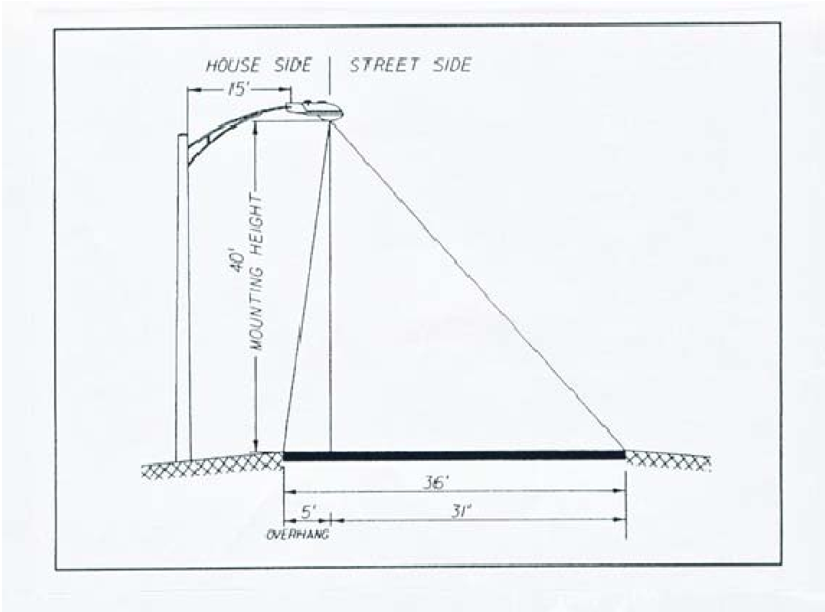
Generally, overhang fixtures will provide the most amount of street side lighting while minimizing house side lighting. However, these fixtures are often more difficult to maintain because the luminaire is located over the lane of traffic.

Fixtures on the roadway edge and offset will provide less street side lighting and more house side lighting than the overhang fixture. However, maintenance is easier because the luminaire is not located over the travel lane.

The following illustration shows an overhang luminaire.



The following illustration shows an overhang luminaire spilling light to the street and house sides. Roadway lighting that spills over to the house side is also known as light trespass.



I. Photometric Data

The luminaire manufacturers have photometric data sheets for each type of lamp. These data sheets contain valuable information for the lighting designer. It contains the luminaire name and reflector and refractor numbers. Also included are lamp wattage and type of cutoff. This information is used to create a simulation of a utilization curve and isofootcandle curves. These tables show the difference in the amount of light distributed to the street side and house side of the luminaire. This information assists the designer in determining if the proper cutoff fixture is being used for the specific application.

J. Basic Lighting Equations

The following equations can be used to calculate roadway lighting spacing.

SP = (LL x CU x MF) / (FC x W)

(English): SP = (LL x CU) / (FC x W), where FC = Footcandles = Lumens/Square Foot

(Metric): SP = (LL x CU) / (LUX x W), where Lux = Lumens/ Square Meter

Abbreviations:

FC = Footcandles

LUX = Light level on the roadway

LL = Lamp Lumens

CU = Coefficient of Utilization

MF = Maintenance Factor

W = Roadway Width

SP = Spacing

Summary

Objectives for roadway lighting were provided. Lighting equipment was listed and defined. Luminaire components, luminaire supports and bracket arms were discussed.

Conventional, high mast, sign and underdeck lighting requirements were identified.

Design criteria for roadway lighting was discussed. Lighting terminology was defined. Different spacing arrangements were shown.

IES lighting distribution and types of light cutoffs were discussed.

Finally, basic lighting equations were provided.

This course should assist an engineer in the planning and design of roadway lighting plans.