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Understanding Outdoor LED Electronic Signs

A report on current outdoor LED sign technology by Adaptive Micro Systems LLC.

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Advertising signs play an important role in driver wayfinding. Well-placed and well-designed advertising signs can guide a vehicle operator toward the individual's destination with minimal attentional demand, whereas poorly visible advertising signs can sap a driver's cognitive and perceptual resources.

As an integral part of the navigation function, advertising signs are a necessary traveler aid.

— from Sign Visibility Research and Traffic Safety Overview, USSC, 1996

Purpose

- To explain the basic terms and concepts of light and human sight that are necessary for an understanding of outdoor LED sign technology.
- To examine the variables involved in selecting an outdoor LED sign.

Contents

Signs

Light

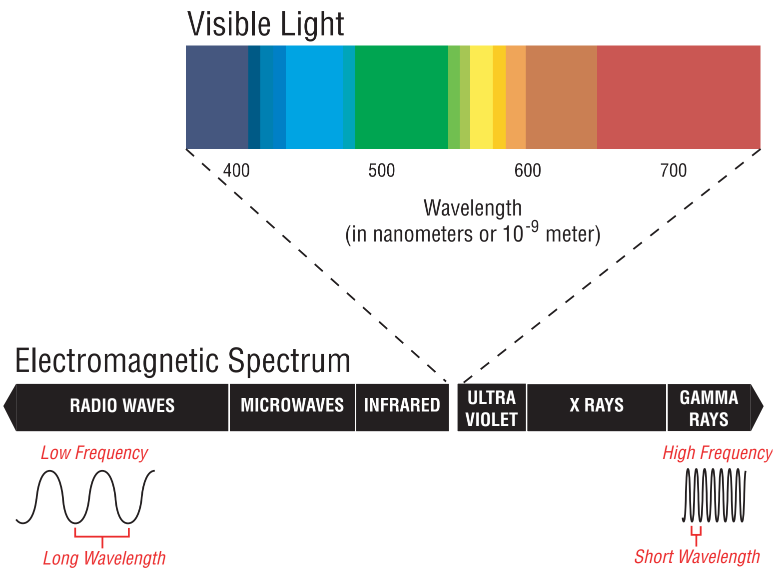
It goes without saying that light is *the* essential element of LED signs, outdoor or indoor. Therefore, a basic knowledge of the fundamentals of visible light and how it is measured are necessary to fully understand outdoor LED sign technology.

We've come a long way in our understanding of light and human perception. The Greek philosophers believed that light emitted *from* our eyes to illuminate the outside world, and it wasn't until the 17th century that correct drawings of the human eye were made. However, during this same century, the science of optics was invented by Johannes Kepler and the visible light spectrum was discovered by Isaac Newton.[1]

ELECTROMAGNETIC SPECTRUM

Using a prism, Newton was able to demonstrate how visible light could be divided into its component colors. This visible light spectrum, however, is just a small part of the much larger electromagnetic radiation spectrum which includes everything from low frequency radio waves (also television) to very high frequency gamma rays:

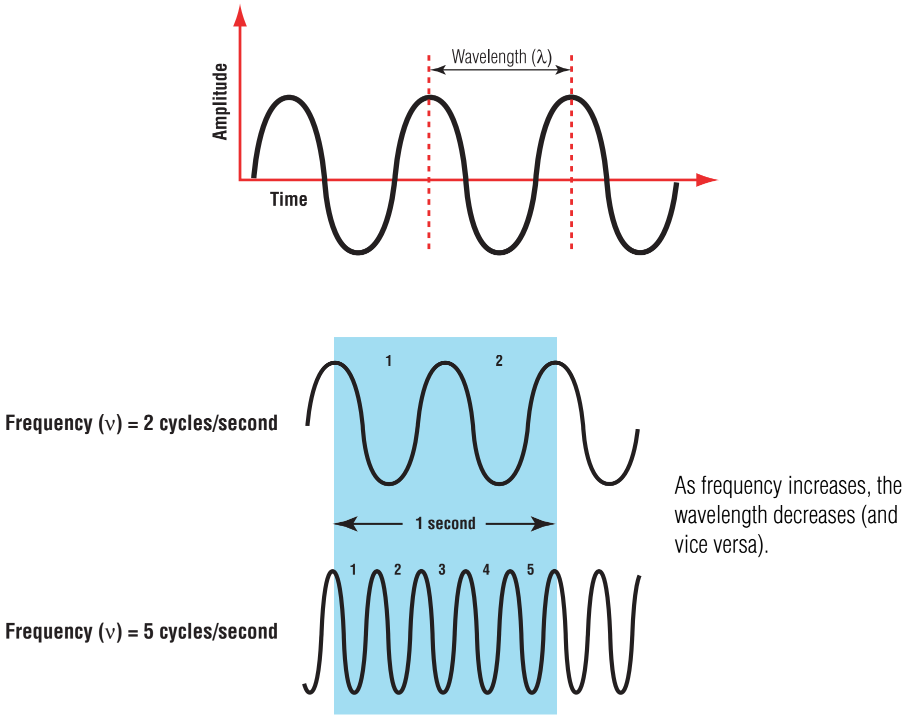
FIGURE 1. Electromagnetic spectrum



LIGHT MEASUREMENT

Two key terms used in light measurement are *wavelength* and *frequency*. Because light travels in waves, it is possible to measure the distance between waves (wavelength) and how many waves pass a given point in one second (frequency). Wavelength and frequency are inversely related — when one increases, the other decreases: For example, high frequency waves have short wavelengths, and low frequency waves have long wavelengths.

FIGURE 2. Wavelength and Frequency



As frequency increases, the wavelength decreases (and vice versa).

Though we normally use terms like “red”, “blue”, “green”, etc. to describe a color, more precise terminology is often necessary, particularly in LED electronic signage. In this case, wavelength is used to provide an exact color description. For example, the red LEDs used in Adaptive’s AlphaEclipse™ signs have a wavelength of 626 nanometers (nm). Human vision falls between 400 and 700 nm (see Figure 1 on page 3) and in a well lit environment is maximally sensitive to light at 555 nm (yellow-green) but relatively insensitive to far red and blue light.[2] Though wavelength can precisely describe a color, *color perception* depends on other factors such as hue, saturation, and brightness.[3]

Radiometric measurement

In addition to measuring the color of light, there are two systems for determining the intensity or “brightness” of light: radiometric and photometric. Both methods take into account direction and surface.

Radiometric units specify the amount of radiant energy present in light, and radiometric measurements are expressed in either watts or joules. Terms used in this system include Radiant Flux, Radiant Intensity, Irradiance, and Radiance.

TABLE 1. Radiometric terminology[12]

Term	Symbol	Application	SI unit
Radiant Flux (or Radiant Power)	F_e (P_e)	Total quantity of light emitted from a source.	watt = joule/sec (W)
Radiant Intensity	I_e	Total quantity of light emitted by a point source in a given solid angle.	watt/ω
Irradiance	E_e	Density of light incident on a surface or in a given plane.	watt/m^2
Radiance	L_e	Amount of light emitted or reflected from an extended source in a given direction.	watt/ω/m^2

Photometric measurement

For our purposes, photometric measurement is the preferred method of calculating light intensity because it is a system based on the impact of light on a human observer. Photometric units specify the capacity of radiant energy to evoke a visual response.

TABLE 2. Photometric terminology[12]

Term	*Symbol	Application	SI unit
Luminous Flux	F or F_v	Total quantity of light emitted from a source. Luminous Flux is derived from Radiant Flux.	Lumen (lm)
Luminous Intensity	I or I_v	Total quantity of light emitted by a point source in a given solid angle.	candela (cd) (lumens/ω)
Illuminance	E or E_v	Density of light incident on a surface or in a given plane.	lumens/m^2 (lux)
Luminance	L or L_v	Amount of light emitted or reflected from an extended source in a given direction.	cd/m^2 nit (nt)

* The subscript “v” is often added to denote that this measurement system deals with wavelengths that are visible to the human eye.

Sight

A brief tour of the anatomy and psysiology of the human eye along with some theories of perception will help our understanding of how people see signs.

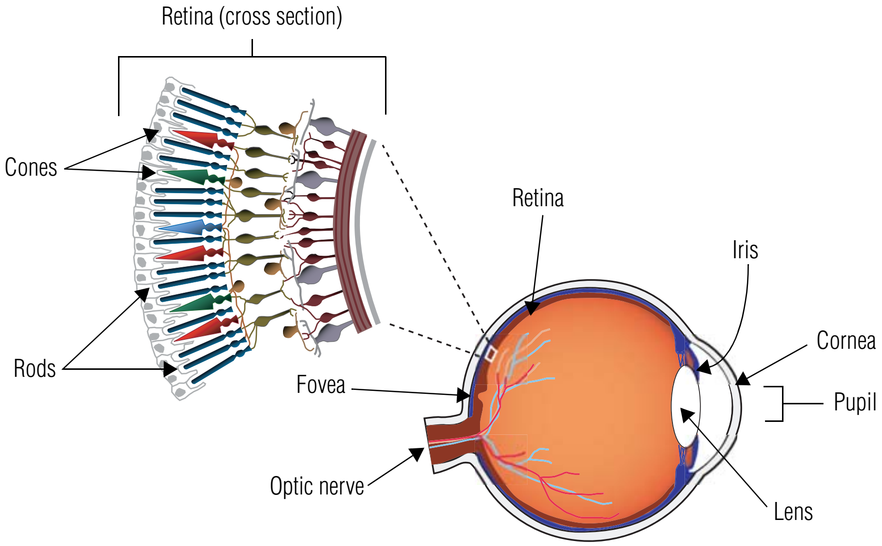
HUMAN EYE

What we know about the eye and vision has been learned largely as the result of “reverse engineering” — that is, by scrutinizing the eye itself. While our understanding of the workings of the eye dates back to the 17th century, our knowledge of perception, or how images from the eye are transformed into meaningful patterns, is fairly recent. It has only been in the 20th century that x-ray, PET, and MRI scans have allowed us to look into the brain to see how it receives and decodes information from the eye.

Eye anatomy

The optic properties of the human eye are similar to those of a camera: to gather reflected light from an image and to bring the image into focus.

FIGURE 3. Anatomy of the eye

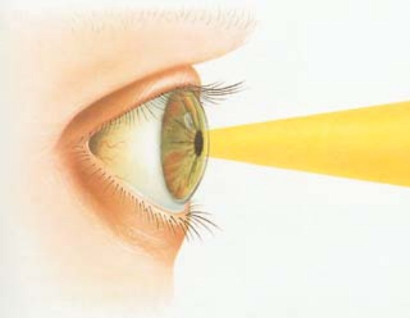


Part	Description
cone	Photoreceptor cell used for normal lighting (photopic conditions).
cornea	Transparent bulge in the front of the eye.
fovea	Small region in the center of the retina which contains nothing but densely packed cone cells. Most of the eye’s 8 million cones are located in the fovea.
iris	Variable-shaped opening which regulates the amount of light entering the eye. Eye color is determined by the iris.

Part	Description
lens	Used to focus. Small muscles attached at either end of the lens change the shape of the lens which brings objects into focus.
pupil	The variable-shaped opening in the iris.
optic nerve	Carries visual information out of the eye and into the brain.
retina	Curved, back part of the eye which converts light into electrochemical information and sends it to the brain via the optic nerve. The retina is made up of photoreceptor cells called rods and cones (both of which actually face away from incoming light).
rod	Photoreceptor cell used exclusively in low light situations (scotopic conditions). There are about 120 million rods in the eye.

Cone of vision

The fovea is a small region on the back of the eye that is densely packed with cone cells. Though the visual angle covered by the fovea is only about 2 percent, this area plays an important role in spatial and color vision.[4] Outside the fovea the number of cone cells is much lower, but constant across the entire visual angle. The number of rods, however, drops off dramatically outside a visual angle of 20 degrees. Research done with automobile drivers, who are the target audience for probably most outdoor signs, indicates that signs located *inside* a driver's optimal "cone of vision" might be noticed while those placed outside this cone will not be.



Cone of vision
An area extending from the eyes in which vision is most acute.

Automobile driver research indicates this area is defined by an angle between 10 to 35 degrees.[5]

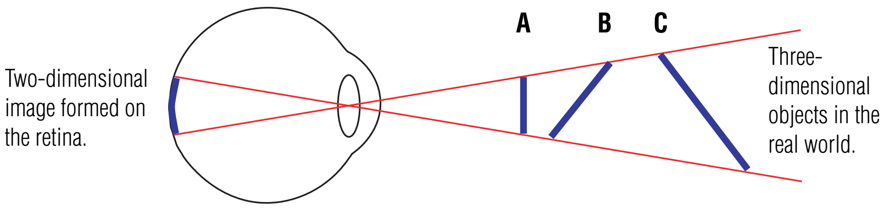
PERCEPTION

The optical properties of the eye are relatively straightforward and are really just the "mechanics" of vision. Our brain has the task of interpreting the information from our eyes. How images from the eye are perceived by our brain is a complex process and still not fully understood. We do know that information from the left eye goes to the right half of the brain and information from the right eye goes to the left side of the brain. The occipital lobe of the brain is the receiving area for this visual information, most of which comes from the eye's fovea. This means that the central portion of a person's visual field receives the most attention in the brain — again, the importance of locating a sign within this cone of vision. We also know that there are areas of the brain used for identifying objects (a “what” system) and for locating objects (a “where” system). Though there is probably a “what-where” connection in the brain, where it is and how it operates are unknown.

However, our lack of understanding does not prevent us from making sense of the world and our brain does this based on limited information from the eyes.

For example, a classic illustration of this is called the “inverse problem” which demonstrates how the brain is able to convert two-dimensional images received from the eye into our three-dimensional perception of the world.

FIGURE 4. The Inverse Problem



Because three-dimensional objects are mapped onto the two-dimensional surface in the our eyes, three poles (A, B, and C) of different lengths would create the *same* image in the eye.

Nevertheless, we would probably have no difficulty perceiving the three different objects because of the brain’s ability to reconstruct the three-dimensional world from our eyes’ two-dimensional representation of it.

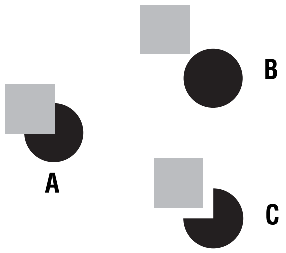
The Inverse Problem is the key to understanding perception because it highlights the gap between the limited optical information received from our eyes and the complete perception of the world we create.

How can we see the world as it is when our eyes only provide us with two-dimensional images? This is not a new question and until we fully understand the psysiology of vision, we have to rely on theories.

Constructivism, the dominant vision theory today, states that “our visual system must be contributing information to that contained in retinal information . . . to arrive at the single most likely possibility from among the logically infinite number of solutions to the inverse problem.” We add information to that given by the eyes, and in a sense, construct the world around us. Constructivism also says that we use rules of thumb and “unconscious inferences” to interpret the world. For example, one rule of thumb, called the “minimum principle”, is that when faced with a number of options, the simplest one is the best.[4]

Most of the time our visual assumptions allow us to see the world as it is.

FIGURE 5. Minimum principle

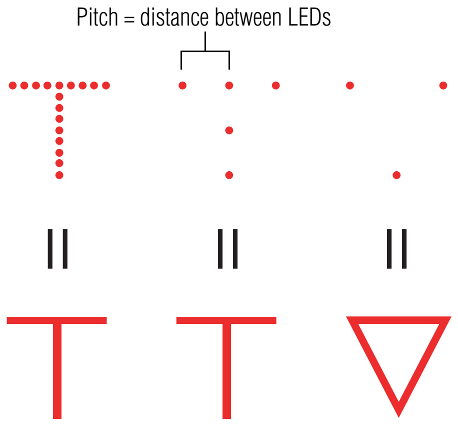


Most people interpret figure A as composed of the two objects shown in B instead of the two in C.

This exemplifies the minimum principle because B is the “obvious” or simplest interpretation.

Our ability to interpret what we see by adding information has a direct bearing on outdoor LED signs. For example, the letters and numbers on LED signs are composed of individual or clusters of LEDs that have spaces between them. This spacing is called pitch. If the number of LEDs on a sign remains the same, then the greater the pitch, the further away a viewer must be in order to read the sign’s text. (LED brightness is also a factor because light helps to bridge the gap between LEDs.) At some point, however, LED pitch could become so great that it would be difficult or impossible to read a message on the sign.

FIGURE 6. Connecting the dots

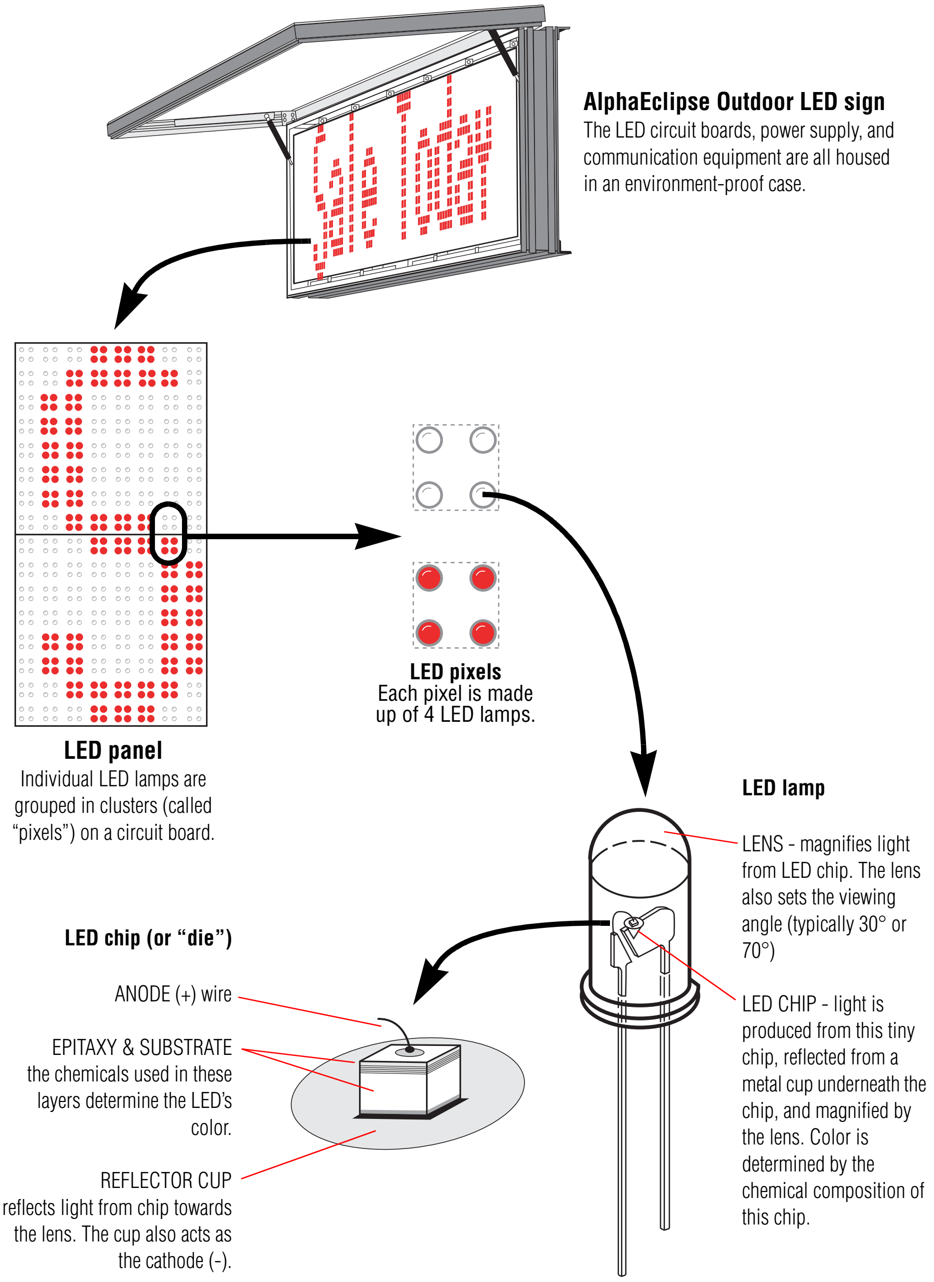


Signs

ANATOMY OF AN LED SIGN

A typical outdoor LED sign is made up of individual LEDs or clusters of LEDs (like below) that are soldered onto circuit boards which are enclosed in a waterproof housing:

FIGURE 7. AlphaEclipse™ outdoor LED sign



AlphaEclipse Outdoor LED sign
The LED circuit boards, power supply, and communication equipment are all housed in an environment-proof case.

LED panel
Individual LED lamps are grouped in clusters (called "pixels") on a circuit board.

LED pixels
Each pixel is made up of 4 LED lamps.

LED lamp

LENS - magnifies light from LED chip. The lens also sets the viewing angle (typically 30° or 70°)

LED CHIP - light is produced from this tiny chip, reflected from a metal cup underneath the chip, and magnified by the lens. Color is determined by the chemical composition of this chip.

LED chip (or "die")

ANODE (+) wire

EPITAXY & SUBSTRATE the chemicals used in these layers determine the LED's color.

REFLECTOR CUP reflects light from chip towards the lens. The cup also acts as the cathode (-).

OUTDOOR SIGN SELECTION VARIABLES

Choosing an outdoor LED sign involves two general selection criteria:

- Visibility
- Value

Visibility

When purchasing an outdoor sign for the first time, many people ask for a specific size of sign like 2 feet by 6 feet. Though dimensions are important factors for print signs like billboards and a cost consideration for electronic signs, the more meaningful question is *How far must the sign be visible?*

First, in terms of visibility and legibility, LED technology outperforms conventional outdoor display systems. In a 1998 Federal Highway Administration study, LED variable message signs (VMS) were readable over greater distances than flip disk and incandescent bulb signs. These results held up for both younger and older drivers, and this is worth noting when considering an outdoor sign because eyesight degrades with age and the typical driver "of the early 21st century will be an individual over the age of 65."[7]

Before a sign can be read, it must first be noticed. A sign's detectability (or "conspicuity") depends on a number of variables, but foremost is *where* a sign placed. Though placement has nothing to do with the sign itself, it is still worth mentioning here because a sign should be located so that it will be seen by the most visible region of the eyes (see "Cone of vision" on page 7).

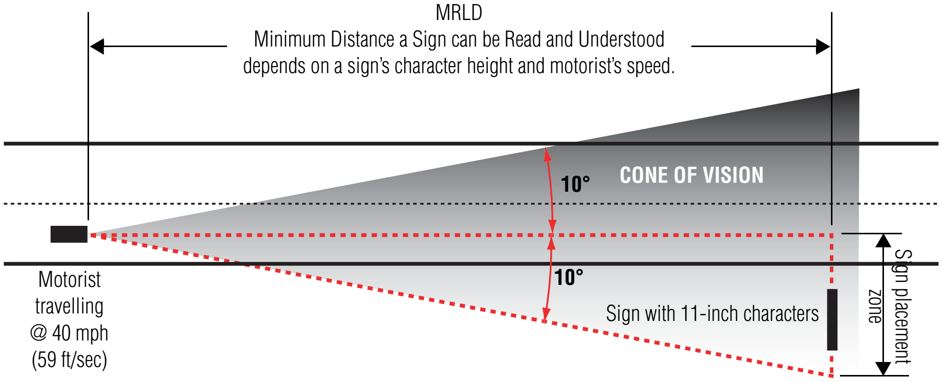
LED signs, as well as the other display types, are not readable over unlimited distances. Fortunately, enough research has been done so that an outdoor sign's reading distance can be calculated with reasonable certainty and this distance can be used to select an outdoor sign.

There are several terms used to define an outdoor sign's visibility (see Figure 8):

- Legibility Index (LI) — the character height of the letters used on a sign is often used as a distance measure of a sign's readability. For example, the often used Federal government standard of 50 feet per 1 inch of character height[8] (LI = 50) means that a sign with 10-inch letters should be readable up to 500 feet (50 x 10). However, this 1978 standard is based on drivers with 20/20 vision and does not take into account the inherent vision loss of an increasingly aging population. An LI = 30 is now recommended because it is based on a decreased vision of 20/40.[5, 6]

- Maximum Required Legibility Distance (MRLD) — defines the minimum distance in which a sign can be read *and* understood. MRLD is computed using driving speed and another variable called Decision Sight Distance (DSD). [5]
- Decision Sight Distance (DSD) — is the time required to read and to understand a sign's message or messages. DSD is highly variable because it is dependent on the *number* of messages on a sign someone must read and on the *content* of these messages. Nevertheless, as a benchmark, previous research of signs displaying 5 or less critical items found that a DSR of 5.5 seconds was necessary for a driver to read a sign's message, understand the message, and then act on the message.[5]

FIGURE 8. How far must the sign be visible?



In this example, the sign has 11-inch characters which can be read *up to* 330 feet (with a LI of 30, it's 11 x 30).

A motorist on this 40 mph road needs at least 323 feet to read and understand the sign (with a DSR of 5.5 sec, it's 59 ft/sec x 5.5 sec). This 323 feet is the MRLD.

The Sign Placement Zone (also called "lateral offset") is the optimal viewing area for a sign because a sign

TABLE 3. Sign selection guide

Someone travelling in a car at . . .		Needs this MRLD (see NOTE)	Then select a sign with . . .	
MPH	ft/sec	ft	Character size (in)	Lateral offset (ft)
75	110	605	20	0 - 53
70	103	565	19	0 - 50
65	95	524	17	0 - 46

TABLE 3. Sign selection guide

Someone travelling in a car at . . .		Needs this MRLD (see NOTE)	Then select a sign with . . .	
MPH	**ft/sec**	**ft**	**Character size (in)**	**Lateral offset (ft)**
60	88	484	16	0 - 43
55	81	444	15	0 - 39
50	73	403	13	0 - 35
45	66	363	12	0 - 32
40	59	323	11	0 - 28
35	51	282	9	0 - 25
30	44	242	8	0 - 21
25	37	202	7	0 - 18

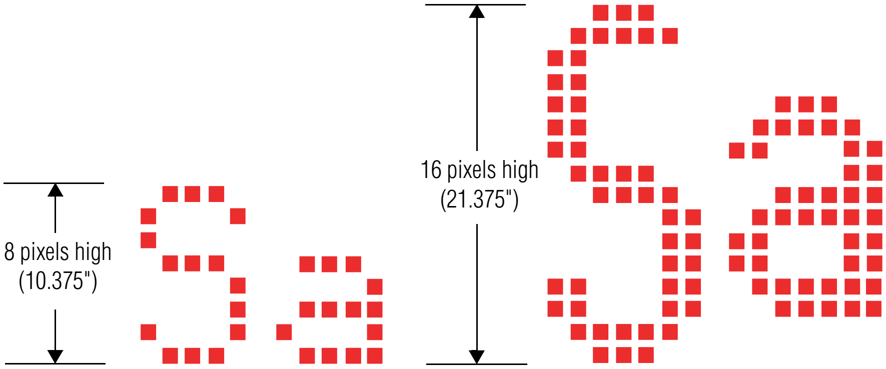
NOTE: MRLD (Minimum Required Legibility Distance) — is the minimum distance required for a sign to be readable. This is based on the Legibility Index (LI) used. In this table an LI = 30 is used. This means that for each 1-inch of character height, a sign can be read up to 30 feet. For example, with LI = 30, a 10-inch character is readable up to 300 feet (30 x 10). Until recently an LI = 50 was the “gold standard”. However, this value is based on someone with 20/20 vision. Today, with an ageing population, a more realistic value would be LI = 30 which is based on someone with 20/40 vision.

Value

We can determine the value of an outdoor LED sign by comparing it with other outdoor sign technologies — specifically, incandescent lighting. For comparison, we can examine the quality and cost of LED and incandescent signs.

Workmanship, one measure of quality, is difficult to use because it varies from manufacturer to manufacturer and also from sign to sign. However, sign readability (or *legibility*) is a more objective point of comparison between LED and incandescent signs.

The size of characters used in a sign is the key measure of legibility. For example, on the AlphaEclipse™ LED sign, character size ranges from about 10 inches on a one-line sign to 21 inches on a two-line sign:



One-line
AlphaEclipse™ sign character

Two-line
AlphaEclipse™ sign character

The following table shows the results of a 1991 study on both day and night legibility distances for various sign technologies for both younger and older drivers[7]:

Sign technology (character height)	**Daytime legibility distances (ft)**		**Nighttime legibility distances (ft)**	
	Younger observers	**Older observers**	**Younger observers**	**Older observers**
Fiber optic (16 in)	1006	959	687	667
LED (17.8 in)	*812*	*681*	*794*	*602*
Flip disk (18 in)	731	667	363	348
Incandescent (18 in)	800	671	750	569
Hybrid LED/flip disk (18 in)	731	667	794	602

In all cases, the LED sign was more legible than the incandescent, and in one case (younger observers at night) surpassed fiber optic signs.

Though the cost of purchasing an LED sign may seem expensive when compared to other sign technologies, LED reliability and power savings more than offset this initial cost.

For example, using the following “worst case” assumptions below, after over 11 years of continous use, we can be 98.33% certain that AlphaEclipse™ sign LEDs will *not* need replacing:[10]

- the LEDs are on 100% of the time for 100,000 hours (over 11 years)
- the LEDs are on for 12 hours during the day and 12 hours at night
- during the day the LEDs are exposed to 45°C (113°F) temperatures
- during the night the LEDs are exposed to 5°C (41°F) temperatures

Finally, the amount of energy required to power LEDs is much less than that used by incandescent bulbs. An AlphaEclipse™ sign pixel (a group of four LEDs) uses 40% less power than a comparable wedge-based incandescent light.[11]

References

[1] Polyak. S. (1957) *Vision and Visual Perception*. New York: John Wiley and Sons, Inc.

[2] Kalloniatis, M. & Luu, C. Psychophysics of Vision. In Kolb, H., Fernandez, E., & Nelson, R., *WEBVISION: The organization of the vertebrate retina*. http://webvision.med.utah.edu

[3] Kaiser, P. & Boynton, R. M. (1996) *Human Color Vision*. Opt. Society of America.

[4] Palmer, S. (1999) *Vision Science.* Cambridge: MIT Press.

[5] Garvey, P, Thompson-Kuhn, B, & Pietrucha, M. (1996) *Sign Visibility Research and Traffic Safety*. United States Sign Council.

In this study, a search of driver visual field literature suggested that a sign be placed within 10 degrees of a driver's line of sight.

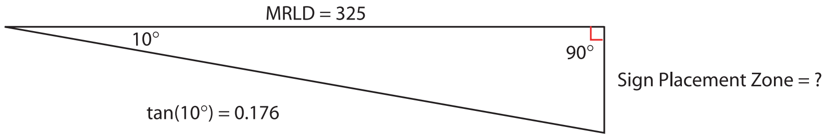
[6] Oregon State University. (1994) *The Development of Ergonomic Guidelines for Electronic Customer Information Systems.* US Department of Commerce, National Technical Information Service.

This study states that sign should be located in an "optimum" driver visual field of 15 degrees.

[7] Turner-Fairbank Highway Research Center. (1998) *Older Driver Highway Design Handbook*. Washington, DC: FHWA, US Department of Transportation, Federal Highway Administration publication no. FHWA-RD-97-135.

[8] *Standard highway signs*: as specified in the manual of uniform traffic control devices (1978) Washington, DC: FHWA, US Department of Transportation.

[9] Since the cone of vision is made up of two right triangles, the trigonometric tangent function is used to compute the Sign Placement Zone (or lateral offset):



Sign Placement Zone = $\tan(\theta) \cdot \text{MRLD}$

= $0.176 \cdot 325 = \mathbf{57}$

[10] Agilent Technologies. (1999) *Reliability of Precision Optical Performance AlInGaP LED Lamps in Traffic Signals and Variable Message Signs*. Application Brief I-004.

Reliability, or R(%), was calculated using this equation:

$$R(\%) = [e^{-(\lambda_1 t_1 + \lambda_2 t_2)}] \bullet 100$$

with the following assumptions about AlphaEclipse™ sign LEDs:

- direct-driven, not strobed
- on 100% of the time (100,000 out of 100,000 hours)
- on for half of the time during the day (t_1 = 50000) & half at night (t_2 = 50000)
- operates in the daytime at 45°C, the LED MTBF (λ_1) = 0.0003/1000 hours
- operates in the night at 5°C, the LED MTBF (λ_2) = 0.000037/1000 hours

Plugging in these values yields:

$$R(\%) = [e^{-(0.0003/1000) \bullet (50000) + (0.000037/1000) \bullet (50000)}] \bullet 100$$

$$R(\%) = [0.9833] \bullet 100$$

$$R(\%) = 98.33\%$$

[11] Each pixel (4 LEDs) in an AlphaEclipse™ sign uses 0.5 Watt of power. By comparison an incandescent bulb in an Alpha® 790i sign uses 1.25 Watts.

[12] Agilent Technologies. (2000) *A Guide to Human Visual Perception* and the *Optical Characteristics of LED Displays.* Application Brief D-004.

Glossary

candela (cd) — see luminous intensity.

CIE (Commision Internationale de L'Eclairage) — develops standards for measuring light.

CMS — Changeable Message Sign. Another name for electronic sign. This term is often used by the US Department of Transportation.

conspicuity — a term used for sign detection, the ability of a sign to attract attention and be noticed from its surroundings.

detection — see conspicuity.

illuminance — expressed in lux (lx), the amount of light that reaches a surface from a light source. This measurement is affected by distance ($lx=cd/d^2$). For example, if a light source emits a luminous intensity of 36 candela (cd), the illuminance at 3 meters would be 4 lx ($4 = 36/3^2$).

legibility — the ease with which a sign's content can be read.

Legibility Index (LI) — used to describe the distance a sign can be read for different letter heights, measured in feet per inch of letter height (ft/in). For example, a sign with 10-inch high lettering, legible at 400 ft, has an LI of 40 ft/in (400/10).

luminance — expressed in candelas per square meter (cd/m^2) or nits (nt), luminance is a measurement of either emitted or reflected light and is the photometric that comes closest to what people term "brightness". This measurement is not affected by distance.

luminance contrast — effects both legibility and conspicuity and is either internal or external contrast. The ability of a sign to catch your attention (conspicuity) is effected by external contrast which is the ratio of the sign's average luminance and the luminance of the area directly surrounding the sign. Legibility distance is effected by internal sign contrast, defined by the ratio of the luminance of a sign's content and its background.

lux (lx) — see illuminance.

luminous intensity — expressed in candelas (cd), a description of the light source itself. This measurement is independent of distance; that is, no matter how far away you are from a light source, the source will always have the same luminous intensity.

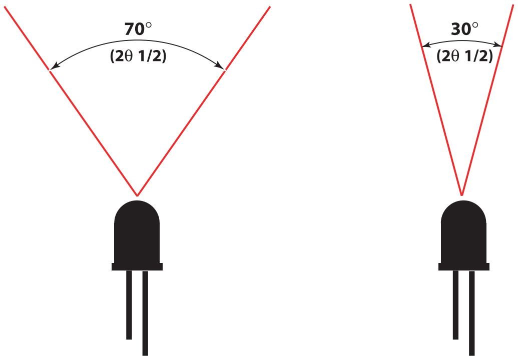
photometry — the measurement of light. Photometric equipment is designed to measure light in terms of how people see light.

reflectance — expressed as a percentage, is the ratio of illuminance to luminance. For example, if 100 lx strikes a surface that has a luminance level of 5 cdm^2, then that surface has a reflectance of 5% (5/100).

retroreflection — expressed as either coefficient of retroreflection (R_a) or more commonly as SIA (Specific Intensity per unit Area). The SIA of a material is the ratio of reflected light to incident light, commonly expressed as candelas per lux per square meter (cd/lx/m^2).

SI (Systéme Internationale d'Unités) — a standardized measurement system derived from the metric system. The basic SI unit of length is the meter, of time the second, and of mass the kilogram.

viewing angle — the angle that defines the area of maximal brightness of an LED lamp. Outside the viewing angle brightness is greatly reduced (typically 50% of maximal brightness). The viewing angle is actually a three-dimensional cone in front of an LED. Typical viewing angles are 30° and 70°:



visibility — sign visibility is a determined by its detection (or conspicuity) and legibility. Sign visibility is often defined by the maximum obtainable viewing distance.

VMS — Variable Message Sign. Another name for electronic sign. This term is often used by the US Department of Transportation.