FEDERAL SIGNAL
Safety and Security Systems

Risk Reduction for Emergency Response

Today, emergency responders face more challenges than ever before. Cell phones, powerful car sound systems, and new automotive PC technology increasingly distract motorists. More than ever, public safety officers must count on visual and audible warning systems to help create a zone of safety around an emergency vehicle seeking the right of way.

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Introduction

Though it is not generally the first thing people think of when they consider the hazards faced by police, fire and medical emergency responders, vehicular accidents are in fact a leading cause of on-duty injuries and fatalities. In fact, according to data compiled by the National Law Enforcement Memorial Fund (NLEMF), 2010 marked the 13th consecutive year that more law enforcement officers were killed in traffic-related incidents than from any other cause.

High-speed vehicle operations such as police pursuits and responses to fire and medical emergencies account for a significant percentage of these fatalities. Additionally, in a surprising number of incidents, the emergency responders were engaged in duties outside their vehicles. In the case of law enforcement officers, for instance, this includes routine traffic stops, roadblocks, disaster response, traffic management and roadside accident investigations. Drawing again from NLEMF's data, 16 of the 73 police officers killed in traffic incidents during 2010 were struck by a vehicle while outside of their own vehicle.

A study published by the national Uniform Crime Reporting (UCR) program entitled *Law Enforcement Officers Killed and Assaulted*, *2002* reports that in the period between 1993 and 2002 a total of 681 law enforcement officers were killed accidentally. Of these deaths 381 (55.9%) were the result of automobile crashes. Another 111 (16.3%) of these accidental fatalities occurring during this same 10-year period were the result of officers being struck by a vehicle while performing duties outside of their own vehicle, with 73 of these officers killed directing traffic or assisting motorists, while the remaining 38 were engaged in traffic stops or manning roadblocks. (A subsequent report by the Federal Bureau of Investigation (FBI) confirms this by reporting that 12 of the 13 officers struck by vehicles in 2008 were either directing traffic or assisting motorists.) From 1993 to 2002 an additional 15 officers were killed in fiery rear-end collisions involving their patrol vehicles.

The nation's firefighters are equally subject to the hazards associated with emergency response. A July 2005 study produced by the University of Michigan's Transportation Research Institute for the U.S. Fire Administration (USFA) entitled *Inferences About Emergency Vehicle Warning Lighting Systems from Crash Data* draws information from a specialized database to confirm that 98 firefighters were killed in traffic crash incidents, and nearly one quarter of those firefighters were pedestrians performing their duties at an emergency scene.

Many first responder injuries and fatalities can be traced to the effects of a much more diverse motorist population that now includes a greater number of drivers impaired by drugs, alcohol and fatigue, more aggressive drivers, violent criminals, and an increasing number of elderly drivers with diminished reflexes. The types of vehicles in use on the nation's roadways have also changed dramatically over the past few decades to include a greater number of heavy trucks and sport utility vehicles; and there has also been a general increase in posted speed limits. Add to all this the growing concern over motorist distractions such as cell phone conversations, text messaging, powerful car stereo systems and automotive PC technology and it's not difficult to understand why the nation's roadways are as perilous for emergency first responders today as they have ever been.

Coming under scrutiny in response to the call to reduce roadway risks associated with emergency response vehicles are everything from roadway design, expanded use of reflective materials for vehicle markings as well as personnel clothing, to the audible signaling devices (i.e., sirens and horns) used by police cars, fire trucks and ambulances. For obvious reasons, the warning light systems deployed on emergency vehicles have received particular interest.

Over the past decade a number of government agencies and research organizations have begun to seriously study the effects of vehicle emergency warning lights, with emphasis on such areas as lamp color and intensity, flash patterns, comparisons of warning lamp performance in daytime and nighttime conditions, and the effects that glare and masking may have on approaching motorists. Among these organizations are the Society of Automotive Engineers (SAE), the U.S. Department of Transportation's Federal Highway Administration, the National Institute of Justice (NIJ), the U.S. Fire Administration (USFA), the National Institute of Standards (NIST), and the University of Michigan's Transportation Research Institute.

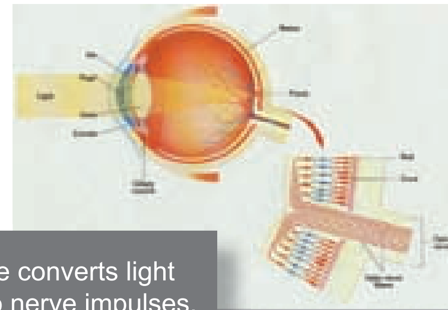
It is important to note that the potential risks associated with the effectiveness of lighting systems deployed on emergency vehicles are hardly limited to the danger posed to first-responder personnel. Other risks include:

- The potential for injuries or fatalities to civilians as well as other public safety officers during a criminal pursuit or response to an emergency call.
- The possibility of rapidly deteriorating medical conditions due to ambulances being delayed in traffic either to or from accident sites.
- Increased property damage or loss resulting from emergency vehicles being delayed in traffic.
- The potential for costly litigation resulting from personal injury or property damage claims resulting from emergency vehicle accidents.

In the simplest terms, these warning light systems are designed to provide the enhanced conspicuity that enables motorists to detect and safely react to the presence of emergency response vehicles on public roadways. This holds true whether the vehicles are in motion or stationary, blocking the normal path of traffic or parked near the path of traffic.

The effectiveness of emergency lighting to warn motorists is determined by a number of factors. Chief among these are lamp color and intensity, flash rate, abruptness of flash onset/offset, number of lamps, and lamp configuration. This white paper will explore these issues and others with the intent of making suggestions and recommendations for lighting systems that effectively reduce the risks associated with first responder vehicle operations. Although the intent of this white paper is to address lighting systems, an effective emergency warning system must include an audible warning device such as a siren system. Therefore, a sidebar has been included to briefly address the subject of audible warning.

The Basics of Human Visual Perception



The eye converts light energy to nerve impulses.

The retina of the human eye contains receptors called rods and cones. The rods are sensitive to movement but not color. The cones support viewing of both detail and color. It is worth noting that the rods and cones are not evenly distributed within the retina. While the center of the retina contains only cones, the peripheral areas are made up primarily of rods. For this reason, activity detected by peripheral rods will signal the brain to move the head and eyes so that the center cones can focus on the perceived activity.

Peripheral vision is critical to the task of driving. As an emergency vehicle travels at higher speeds the driver's ability to detect motion in the peripheral-vision field is correspondingly reduced. A visual tunnel effect results as the driver's attention is drawn to more stationary objects in the visual field, and away from the "streaming" (peripheral) field of view. Consequently, in addition to their own visual perception, operators of emergency vehicles must also rely on warning systems to alert those motorists that are out of sight making them either difficult or impossible to detect.

Travel time is also a critical component of the warning process. As speed increases, travel time for a given distance decreases. To illustrate, at 50 mph it takes only one second to travel 73 feet. This restricts the window of time available to the operator of an emergency vehicle to warn motorists and pedestrians of their approach across a wide horizon. For this reason the audible and visual warning system should warn as wide an area as possible around the vehicle

Factors Affecting Peripheral Vision

Contrast. How much the brightness of a signal differs from the surrounding environment.

Visual Workload. Describes the number and complexity of the signaling in the overall visual environment.

Speed. How fast the observer is moving through the environment.

Consequently, for emergency lighting to be most effective it must allow for the signal to be seen at a distance (exhibit high flash energy), and be captured by the peripheral retina (exhibit high-flash activity). Just as importantly, warning lights must be bright and active at many different angles, providing 360-degrees warning around the vehicle.

Signal Interpretation

In reducing the risk of accidents associated with emergency first-responder vehicles, three primary factors come into play:

Detection. This refers to the initial recognition of the signal. Early detection is crucial. Put simply, the sooner the observer detects the signal the better. In urban environments, where line of sight is limited, the audible warning system will most likely be detected first.

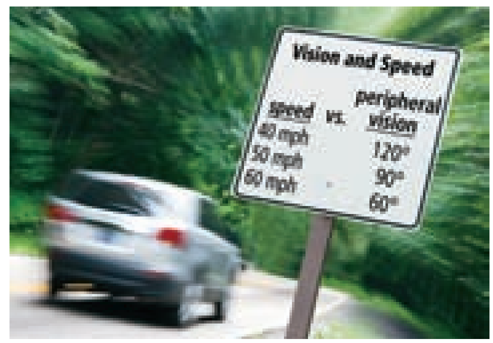
Recognition. After detecting the signal, the observer must determine that it is in fact an emergency warning. For lighting, light color, light pattern and frequency all play a part in helping the observer identify the type of vehicle, as well as the status and direction of approach. In addition to emergency lighting, audible siren signals (i.e. sirens) are repetitive which leads to faster recognition, especially near intersections.

Response. The object of a warning signal is to modify observers' behavior. A "collective knowledge" based in part on driver education and social conditioning generally prompts motorists to yield and respect the sight and sound of approaching emergency vehicles by either pulling off the road and stopping, or moving to the right. Ideally, emergency signals should not only *warn* motorists, but also *inform* them by providing direction that the observer can interpret and then react to, but in situations where the vehicle is asking for the right of way, this is not always possible.

Design Factors for Emergency Warning Systems

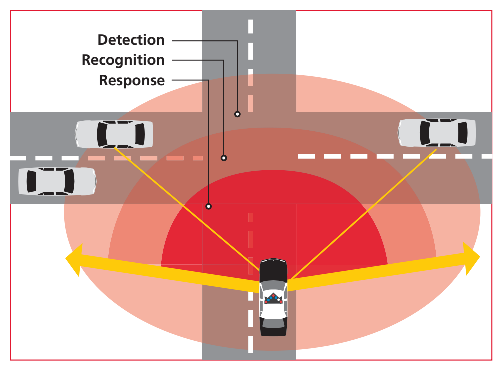
In addition to meeting regulatory standards, emergency vehicle warning equipment must be engineered, built and tested to address a broad variety of human factors. Here are just a few examples:

- For every 10 mph increase in speed, a driver's peripheral vision may decrease by as much as 30 degrees. (Fig. 1)
- The overwhelming number of accidents involving emergency vehicles occur at intersections.
- Law enforcement engages in thousands of pursuits each year with many resulting in property damage and/or injuries.
- High adrenaline levels that accompany high-speed, hazardous driving may impair judgement thereby requiring warning systems to be easy to use.



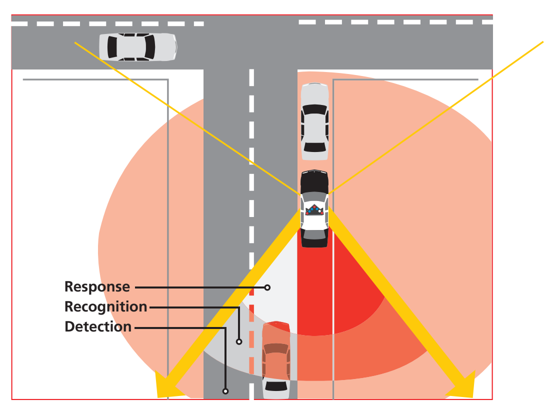
Effects of speed on peripheral vision Fig. 1

As an emergency vehicle approaches an intersection, the driver must be capable of alerting both motorists and pedestrians approaching from all angles. Likewise, motorists must detect and recognize emergency warnings in time to clear a path.



Emergency vehicle in a moving situation Fig. 2

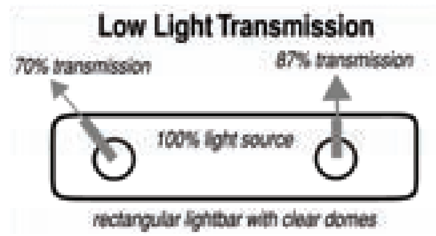
Emergency lighting requirements vary between moving and stationary situations. In a moving situation the emergency vehicle is attempting to request and secure the right of way. The primary task is to warn others approaching the intersection, that an emergency vehicle is approaching. Figure 2 illustrates a moving emergency vehicle and identifies the warning zones in terms of human response to light and sound signals.



Emergency vehicle in a stationary situation Fig. 3

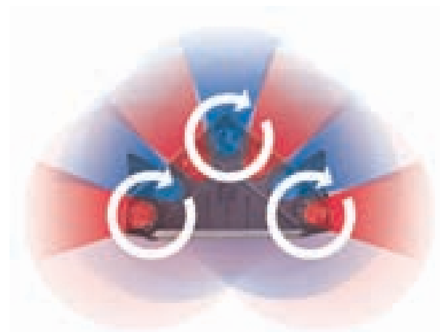
A stationary emergency vehicle poses different kinds of risks (see Figure 3). Traffic must be alerted to the vehicle's location as well as the fact that it is not moving. Generally, the stationary vehicle's light source is attempting to provide a safe zone around and near the vehicle. The primary emergency lighting must provide the design flexibility to address these warning situations as well as common secondary lighting needs like traffic signaling. In the case of police vehicles, it is also beneficial for the emergency lighting system to provide takedown and alley illumination.

The physics of light also plays an important role in the design of effective emergency lighting systems. For instance, light projected on axis through a clear dome will lose approximately 10-13 percent of its transmission energy. By the same token, light hitting a lightbar dome at angles greater than 45-degrees or passing through non-parallel planes will lose considerably more transmission energy (see Figure 4).



Low Light Transmission (Fig. 4)

Another critical design consideration is the use of offset light sources. Offset lights are more effective at projecting light on approach to intersections. This is due to greater side projection and reduced light blockage (see Figure 5).



Off-set light sources (Fig. 5)

Activity, or flash rate, also plays an important role as “faster” signals are perceived as “more urgent”, and in certain situations, the operator may feel a “more urgent” signal is appropriate. This is another reason why it is generally considered critical for emergency signals to supply a high degree of flexibility.

Standards for Emergency Vehicle Visual Warning Signaling

There are a number of industry and governmental bodies that publish standards for emergency vehicle warning equipment. A few of the industry standards include:

- **SAE** - Society of Automotive Engineers
- **CCR -** (Title 13) California Code of Regulation
- **NIJ** - National Institute of Justice
- **NFPA** - National Fire Protection Association

These standards, developed by experts from both the public and private sectors, typically describe minimum requirements for effectiveness. For visual warning devices, SAE-recommended practices are most commonly accepted. Emergency vehicles responding to emergency situations should have SAE Class 1 primary warning lamps with 360-degree coverage.

SAE requirements include general environmental performance criteria for vibration, moisture, corrosion, etc. (SAE J575). Also provided are specific photometric requirements for rotating, oscillating, and stationary devices (SAE J845 and J595). California’s Title 13, Article 22 that addresses warning lamps closely parallels SAE but is notable in its requirement for “steady burning” red lamps. The most comprehensive SAE specifications (SAE J2498), specifies total vehicle warning lighting system requirements.

Key Areas of Scientific Research in the Field of Emergency Vehicle Lighting

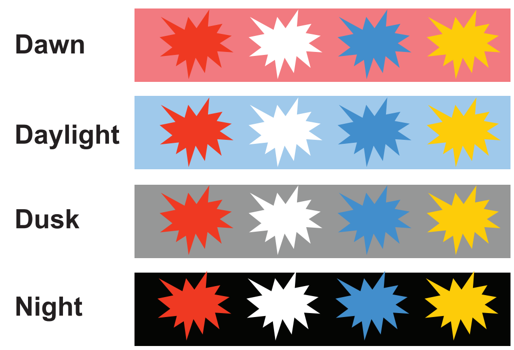
As noted previously, substantial research has been conducted with regard to warning lighting systems for emergency first-responder vehicles. Two of the more comprehensive studies were produced by the University of Michigan’s Transportation Research Institute: *Effects of Warning Lamps on Pedestrian Visibility* *and Driver Behavior* (April 2007); and *Effects of Warning Lamp Color and Intensity on Driver Vision,* (October 2008). Underwritten by the Society of Automotive Engineers (SAE) with the support of the Department of Homeland Security (DHS), Federal Emergency Management Agency (FEMA), United States Fire Administration (USFA), and the Department of Justice (DOJ), Office of Justice Programs. These studies focus primarily on three specific areas of research relating to the evaluation of emergency vehicle lighting system performance:

- Effects of Warning Lamps on Pedestrian Visibility and Driver Behavior
- Effects of Color and Intensity of Warning Lamps on Driver Vision
- Effects of Warning Lights in Daytime and Nighttime Operations

Warning Light Color

The Debate over Blue vs. Red

The differences in ambient light between night and day are so stark that it stands to reason that the effects of different warning lamp colors in both daytime and nighttime conditions would correspondingly be just as straightforward. Understanding the importance of color and intensity have become especially important with the growing use of LEDs as light sources for emergency warning lighting.



The conspicuity of warning lamps at night, contrasted against a generally dark background, is clearly much higher than during daylight conditions. This is a result of the substantial change in spectral sensitivity that differentiates cone-based and rod-based human vision, thereby assuring that the transition from daytime to nighttime vision will, in most cases, be substantially influenced by the effects of color variation.

Virtually every study of the subject has concluded that blue lamps are more conspicuous in nighttime conditions than other colors, including red. The University of Michigan's Transportation Research Institute's study *Effects of Warning Lamps on Pedestrian Visibility and Driver Behavior* concludes: "A possible practical consequence of the effects of color observed in this experiment is that, at least for nighttime conditions, the blue lamps used in this study showed both higher conspicuity and lower glare effects than red lamps." It is also worth noting, however, that in affirming the effectiveness of blue lamps for nighttime operations, a comprehensive Florida Highway Patrol study, *Emergency Vehicle Lighting & Prototype Evaluation*, March 2004, concluded that this increased effectiveness justifies a reduction in lamp output (intensity), but noted that light levels were not high enough to cause night blindness.

Red lamps are traditionally (if not popularly) perceived to be more conspicuous than blue lamps in daylight conditions. Traditions and popular perceptions aside, University of Michigan's Transportation Research Institute discovered in its most recent research that blue was actually more effective in sunlight conditions than white, yellow or even red. This finding is among the first evidence supporting the use of blue lighting under all ambient lighting conditions. Of course, the filtering of incandescent lights to product blue calls for additional electrical power to increase the light-level intensity necessary to satisfy daytime operations. Due to its high visibility, white light is also effective for emergency lighting applications. Though it does not convey the same sense of alarm or caution of red, blue and amber — colors that are typically associated with emergency lighting — white light can be used in combination with these more traditional warning colors when asking for the right of way.

Collaborating with the Society of Automotive Engineers, the U.S. Fire Administration (USFA) conducted a separate study funded by the National Institute of Justice that also recommends increased overall use of blue lamps for day and night operations alike. Though the conspicuity benefits of blue lamps at night has already been firmly established, the study found that, when test subjects searched for warning lights in daytime, blue was measurably more effective than any of the other colors tested, including red. Based on these results the USFA study also supports increased overall usage of blue lamps for daytime as well as nighttime conditions.

In summary, due to the change in human vision from cones during the day to rods at night, the design of police, fire and medical emergency vehicle lightbars continues to favor combinations of red and blue lamps as an effective means to achieve optimum lighting performance (conspicuity) with reduced side effects (i.e., glare and masking) for both daytime and nighttime operations.

It is important to note that the colors used must be recognized by the public as emergency warning lights. Consequently, changing colors without educating the public first could lead to confusion and reduced recognition.

Different Light Intensities for Daytime and Nighttime Conditions

Though the effectiveness of blue lamps in daytime conditions has become a matter of contention with many police, fire and medical first responders, there has long been universal agreement that warning lamps of higher intensity (brightness) are measurably more effective for daytime conditions, regardless of color. By the same token, the issue of motorists being temporarily blinded or pedestrians being "masked" by high-intensity warning lights used at nighttime continues to fuel debate (or at least prompt calls for further research). This explains the growing interest in the need to strike a balance between the high-intensity lighting that is essential for daytime and the reduced-intensity lighting that could be used for nighttime operations.

Finding a compromise in a single intensity output that is bright enough for daytime but still addresses the special glare and masking issues associated with night operations is a difficult task that, at least for some, may entail unacceptable performance trade-offs. For this reason, several research studies have suggested that employing at least two different levels of light intensity may be the best solution to avoiding a trade off that even mildly compromises conspicuity performance and safety issues.

Based on the results of their experiments, and taking into account past research and practical experience, Professor Michael J. Flannagan of the University of Michigan's Transportation Research Institute, explains that limiting warning lamps to a single intensity, "...appears to require a compromise between having lamps that are intense enough for daytime conditions and lamps that are not too intense for night conditions." He goes on to say: "While it may be possible to fine-tune a single compromise level to produce the best overall effect, using at least two levels [one for daytime and another for nighttime conditions] would probably be better than the best possible compromise." Flannagan suspects future research may well prove that it would be even more advantageous to incorporate a much broader menu of intensity level options adapted to a more tightly defined set of ambient light conditions (e.g., higher intensity levels in full sunlight than in daytime cloudy or foggy conditions; and further adjusted intensity levels to compensate for the lack of contrast against ambient light at dawn and dusk).

Adapting warning light intensity to ambient lighting conditions is not a new idea. However, in quantifying differences by analyzing performance between day and night operations, current research data adds weight to the argument in favor of some form of adaptation approach. At least at this point in time, there are some drawbacks — not the least of which have been cost and reliability. There is also the potential for misuse by vehicle operators choosing to always opt for the higher daytime intensity levels, and even override automatic controls (including covering light sensors) because of some operators' personal perception that brighter levels are more effective.

Flannagan responds by pointing to recent technological developments that may offer effective alternatives in addressing these potential drawbacks. Chief among these alternatives are the more economical and extremely reliable LED light sources that can be readily adjusted to produce multiple light levels from the same lamps. In addition to the substantial improvement in warning system flexibility available through LEDs, better automatic controls for day and night conditions may soon encompass sensing of time and position from increasingly more affordable GPS (Global Positioning Systems) satellite capabilities.

In terms of suggestions regarding emergency vehicle lighting, the Transportation Research Institute's *Effects of Warning Lamp Color and Intensity on Driver Vision* focuses on two key considerations. First, the need to evaluate the benefits of varying lamp intensity levels between day and night operations. And secondly, acknowledging the potential for increasing the overall use of blue for all operations — both daytime and nighttime.

Moreover, "The apparent advantage of blue for conspicuity would seem to favor the broader use of blue warning lamps on all types of emergency vehicles," says Flannagan, noting that this has long been the case in Europe. Beyond the basic visibility performance criteria that was the primary subject of his organization's research, Flannagan goes on to suggest that practical considerations, such as the capability of today's LEDs to produce effectively conspicuous blue light relatively easily in comparison with the previous option of filtering incandescent white bulbs, further supports the broader use of blue lighting.

The glare produced by warning lamps used at high intensity light levels, often referred to a s night blindness, is certainly an issue with regards to motorist visibility. Based on his organization's research, however, Flannagan points out that nighttime "masking" is only one factor that impairs visibility.

Beginning with the premise that motorists' vision is inherently impaired in nighttime conditions, and that automotive headlamps are generally considered to be insufficient remedy, *Effects of Warning Lamp Color and Instensity on Driver Vision* points out that even with no glare at all, visibility of pedestrians without retroreflective markings is very poor. The study goes on to emphasize that when pedestrians are equipped with adequate retroreflective markings even very high levels of warning lamp glare may not reduce visibility below acceptable levels.

Another note to keep in mind is that when asking for the right of way, even at night, maximum light intensity may provide the greatest level of warning around the emergency vehicle.

High-Flash Patterns Increase Conspicuity

In addition to lamp color and intensity, flash patterns are another critical aspect of increasing conspicuity of emergency vehicle lighting. Explaining that short-duty patterns (faster, multiple bursts of light) not only improve overall conspicuity, Flannagan concludes that they also convey a sense of urgency that is readily perceived by motorists.

Additionally, *Effects of Warning Lamps on Pedestrian Visibility and Driver Behavior* indicates that, in addition to their higher subjective attention-getting ratings, flashing lights may also help to reduce the negative effects of glare. The study cites the periods between the high-intensity flashes (when illumination diminishes substantially but does not completely disappear), thereby enabling drivers to see without experiencing the full effects of glare.

The Three Types of Light Sources Currently Being Used for Emergency Vehicle Lightbars

Halogen Lamps. Operating similarly to standard incandescent light bulbs found in the home, halogen lights employ a heated tungsten filament that is enclosed in a special gas mixture to improve light output. The combination of the halogen gas with the tungsten filament results in a chemical reaction known as the halogen cycle that increases the lifetime of the bulb, and prevents darkening by redepositing tungsten from the inside of the bulb back onto the filament. Halogen lamps offer greater efficiency by operating their filaments at higher temperatures than a standard gas filled incandescent of similar power without a reduction in operating life.

Strobes. Similar to the strobes used in flash photography, these xenon flash lamps output a very brief but intensely bright flash by ionizing and then discharging a large current through the gas. Also known as gaseous discharge, strobe lights do not use a filament, but instead ignite enclosed gases by means of electron transfer. The fuschia-pink color common to red strobes results from producing light of a some what bluish emission spectrum.

LEDs. Based on the semiconductor diode, Light Emitting Diodes create light by moving electrons through specialized materials, much like those used in solid-state transistors. When a diode is forward based (switched on), electrons are able to recombine with holes within the device, releasing energy in the form of photons. In an effect known as electroluminescence, the color of the light (corresponding to the energy of the photon) is determined by the energy gap of the semiconductor. Usually small in area (less than 1 mm2), an LED employs integrated optical components to shape its radiation pattern and assist in the extraction of photons from the LED.

Reflective Material

Emergency vehicle operations have historically relied heavily on “active” signaling, primarily lighting and audible signals such as sirens. However, “passive treatments using retroreflective sheeting and other materials are increasingly being used to complement lights and sirens. These passive systems include retroreflective markings such as striping and chevrons, high-visibility paints, built-in passive lighting and other devices such as reflectors. The importance of retroreflective materials to improve vehicle visibility and conspicuity is in fact continuing to draw increasing amounts of attention from organizations such as USFA, NIJ, and the Department of Homeland Security’s Federal Emergency Management Agency (FEMA). (For more detailed information on the use of reflective materials in emergency vehicle markings see http:www.usfa.fema.gov/downloads/pdf/publications/fa_323.pdf).

The Growing Popularity of LEDs for Emergency Vehicle Lighting

While halogen bulbs and strobes remain in wide use as illumination sources for emergency vehicle lighting, LED technology is making significant inroads in the design of both lightbars and single beacons.

There are a number of reasons why LEDs are being increasingly incorporated into emergency lighting systems. These include:

> **Compact Size** The reduced size requirements of the LEDs used in lightbar design are well suited to the growing demand for smaller, lower profile, more aerodynamic emergency vehicle lighting systems.
>
> **Greater Efficiency** LEDs produce more light per watt than incandescent bulbs thereby reducing the drain on vehicle battery and auxiliary electrical systems. Additionally, unlike other types of bulbs and tubes, the performance and efficiency of LEDs is unaffected by their size and shape.
>
> **More Intense Colors** Unlike traditional methods of illumination, LEDs do not require filters to produce a variety of strong, intense colors. Because there is no need for any type of filtering to achieve a particular color, LEDs are able to control color better. This is particularly evident with regard to the color blue, which is becoming increasingly popular for a wider variety of emergency warning applications. This ability to produce strong, intense colors without the need for filtering not only makes LEDs more efficient with regard to power requirements, but also reduces initial cost.

According to the University of Michigan's Transportation Research Institute's *Effects of Warning Lamp Color and Intensity on Driver Vision*, "The use of LEDs as effective devices for warning is also backed up by one study that showed point source lamps (in this particular study) were better at eliciting rapid visual responses (conspicuity) than diffuse sources (in the study a neon tube), which one would assume should transfer to halogen bulbs (being a larger surface area would qualify as diffuse) as well."

Faster Onsets/Offsets

LEDs come to full brightness extremely quickly (in some cases in less than a microsecond) making them particularly well suited for first-responder vehicles such as patrol cruisers that oftentimes must activate or deactivate emergency lighting on a moment's notice.

Quicker Cycling

LEDs are used in a variety of applications that call for frequent ON/OFF cycling, and emergency lightbars certainly qualify in that regard. Consequently, LEDs offer a clear advantage over incandescent lamps that require longer intervals between restarting. Faster cycling also translates to extended service life when compared with other types of light sources that burn out quickly when subjected to frequent cycling.

Dimming Capability

LEDs provide the operational flexibility to be dimmed by either modulating the pulse-width modulation or lowering the forward current. This flexibility is especially beneficial in altering the intensity of lighting in order to reduce the effects of glare, night blindness and masking of pedestrians during nighttime conditions.

Extended Service Life

LEDs offer substantially longer service life than other types of lighting sources such as incandescent lamps. The useful service life of LEDs can run anywhere from 10,000 to 50,000 hours, resulting in significantly reduced lightbar maintenance expenses.

Shock Resistance

Since it is not unusual for emergency vehicles to be subjected to rough roads and high speeds, the shock-resistant qualities of LEDs are particularly beneficial, especially when compared to much more fragile incandescent bulbs and glass strobe tubes.

Predictable Failure

As opposed to incandescent lights that can experience abrupt failure, LED luminosity diminishes gradually by dimming over a period of time. In addition to simplifying maintenance scheduling, this also helps to prevent costly and unnecessary vehicle downtime.

Improved Focus

Unlike larger incandescent light sources used with an external reflector to collect light and distribute it in an effective manner, LEDs smaller size can be readily configured to focus light beams more efficiently on a specific point, and thereby direct light to where it's needed most.

Greater Flexibility in Flash Patterns

In choosing light sources for their studies, research organizations such as the University of Michigan's Transportation and Research Institute stress the flexibility of LEDs along with their efficiency and packaging. In fact, when compared with other light sources, LEDs support a much broader range of long- and short-duty flash patterns. The flexibility to readily accommodate a wide variety of flash patterns enables LED light sources to adapt readily to virtually any emergency warning application.

Lightbar Formats

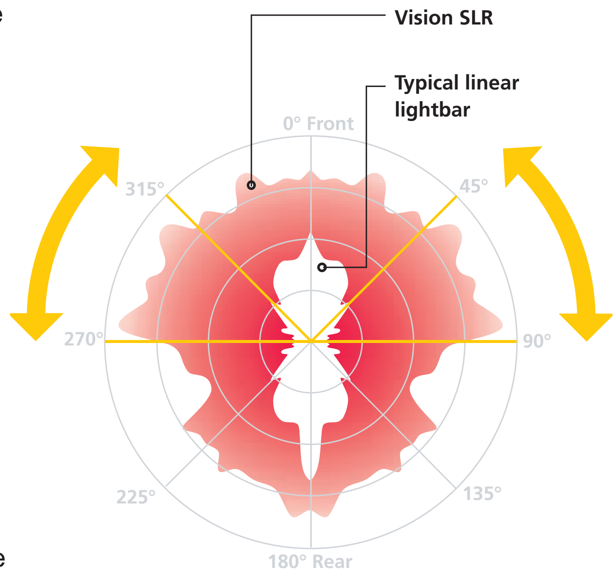
Linear vs. Non-linear

Roadway intersections represent the most significant hazard for first-responder vehicles answering emergency calls. With regard to emergency warning lighting, perhaps nowhere is the need to expand the protection zone for first responders and reduce overall risk to the public more critical.

For an emergency vehicle moving through an intersection the crucial warning zone is located 45- to 90-degrees off-axis.

Traditional "linear" lightbars sacrifice an estimated 40- to 60-percent of their lighting intensity when lamps are directed at extreme angles. This loss in light transmission is the result of the light beams refracting as they pass through the fully enclosed, rectangular dome of the lightbar at severe angles (see Figure 6).

Non-linear lightbars provide improved off-axis warning all around the lightbar, and are particularly effective at critical angles, thereby allowing more time for reaction, and increasing safety for operators and motorists alike.



Off-set light sources (Fig. 6)

For this reason, "V"-shaped offset non-linear light sources are substantially more effective at projecting off-axis/side light on approach to intersections. This is a result of greater side projection in tandem with reduced light blockage. By eliminating critical light loss angles, the non-linear lightbar format inherently ensures that more light is spread out to the extreme angles, where it is needed most.

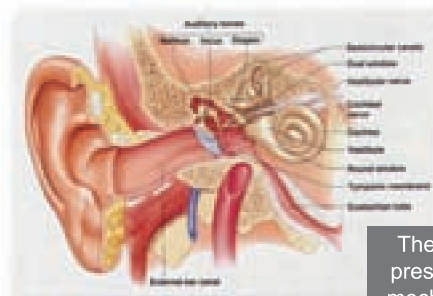
Conventional Linear Lightbar

Non-linear Lightbar

The Basics of Audible Signaling for Emergency Vehicles

Another Vital Component of Early Detection to Reduce Risk for First Responders

The ear converts sound-pressure waves to our inner ear sending electrical impulses to the brain so it can identify the sound. The best way to describe a sound-pressure wave is to think of it as a home theater system, many of which have a sub woofer. If you are standing close enough to the sub woofer you can actually feel the air movement of the low frequency sounds such as drums or explosions. The same happens for high frequencies such as opera vocals, but the body cannot feel the sound-pressure waves. The ear, however, is sensitive enough to detect both low- and high-frequency sounds, but overall the ear is best at hearing sounds in the middle range.



The ear converts pressure waves to mechanical waves.

Sound is measured in decibels. A decibel, also know as dB, is a logarithmic unit that indicates power relative to a reference level. For example, a reference level of “zero” dB is the threshold of hearing (Figure 1). Using specialized equipment, for vehicle siren systems, sound is typically measured at a distance of 10 feet from the source.

As shown in the illustration, 140 dB is the sound of a jet taking off. A Class A siren produces a sound of 119 dB. About midway is the sound of street traffic at 80 dB. Consequently, an audible warning device, while losing sound pressure level as distance increases must produce a sound which is louder than the ambient sound of the surrounding environment. The sound level from the siren will decrease by 6dB for each doubling of distance. That’s why a siren measured at 10 feet must be significantly louder than 80 dB.

Jet Takeoff	140dB
Pain Threshold	120dB
Class A Siren	***119dB***
Rock Group; Jackhammer	100dB
Street Traffic	80dB
Normal Speech; Business Office	60dB
Library	40dB
Forest	20dB
Hearing Threshold	0dB

Fig. 1

To better understand the principles of audible warning, we need to have some basic knowledge of sound measurement as it relates to dB. Humans detect sound-level changes in 3 dB increments.

In order to get a 3 dB change in sound pressure level, it is necessary to double the power of the sound source. This does not mean that the device becomes twice as loud, but rather that a change in volume can be detected.

Another interesting dynamic is that if you double both the power and the source by adding another audible device such as a speaker achieves a 6 dB incremental sound change. A fire apparatus, for example, typically has two speakers, and uses a 200-watt siren that will have 6 dB of improved performance. However, employing a polar plot, a method for measuring and graphing the sound output of a device, it is possible to demonstrate why this does not necessarily result in a more effective warning system.

In addition to the interference of the speakers themselves, another factor to take into consideration when evaluating the performance of an audible emergency signaling device is the competing sounds in the environment.

When using two speakers it is important to ensure that both speakers are operating in-phase. In other words, both speakers need to be outputting the same signal simultaneously. In this configuration, the speakers combine to produce a higher output. This is referred to as constructive interference.

The worst case condition would be phase cancellation. In this case the speakers are operating out of phase with one another. Consequently, the speakers' signals cancel each other out resulting in a reduction in sound output. This is why it is critical to assure that sounds are additive as opposed to subtractive. Put simply, an out of phase system is counterproductive to achieving the desired level of sound power. SAE J1849 addresses the effects of phase cancellation when using dual speaker sirens.

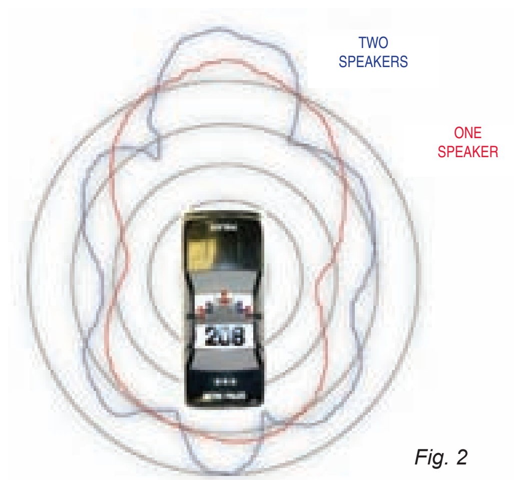


Fig. 2

This Polar Plot (see Figure 2) is measuring a single and dual speaker siren system on a police vehicle. In the center of the graph is a police car accompanied by two colored graphic images that illustrate the sound output and pattern that two speakers versus one speaker produce.

The blue line represents two speakers, and the red a single speaker. There are several key points to consider when looking at these Polar Plots. First, the two-speaker system has more sound energy to the very front of the vehicle, but you start to notice some lobing: when towards the 45-degree angles of the vehicle. And secondly, the single speaker with the red plot produces less sound to the front of the vehicle, but does not have the lobing at 45 degrees in fact, in terms of sound output the single speaker actually outperforms two speakers at 45-degree angles from the vehicle, if the dual speakers are spaced improperly.

Important Consideration in Specifying and Installing Audible Warning Systems for Emergency Vehicles

Since so many first-responder vehicle accidents occur at intersections, it is critical to project audible and visual warning at angles in order to alert oncoming motorists. This is also why it is incorrect to simply assume that a two-speaker system will be more effective than a single speaker system. When mounting audible devices on a vehicle here are several important "must haves" to assure safe and effective sound warning:

- Speakers should be installed low and as far forward as possible on the vehicle.

- Speakers should face the warning zone, and dual speakers should be tested for off-axis phase cancellation per SAE J1849.
- Sound levels in the emergency vehicle's cabin should be in compliance with NIOSH or OSHA noise exposure limits. If you have sound levels above 85 dB(A), you should implement a hearing conservation program.

And finally, employing "wail" or "yelp". These SAE-approved tones cycle through a frequency range in order to improve recognition.

It almost goes without saying that vehicle warning systems need to be regularly tested, with sound output measurements taken both inside and outside the vehicle. During this testing, be sure to use appropriate hearing protection, and follow all approved installation and maintenance procedures as specified by the manufacturer.

Standards for Emergency Vehicle Warning Devices

California Code of Regulations

(CCR) Title 13, Article 22 (includes requirement for "steady burning" red lamps)

Society of Automotive Engineers (SAE)

SAE J595:	Directional flashing optical warning devices for authorized emergency, maintenance and service vehicles
SAE J845:	Optical warning devices for authorized emergency, maintenance and service vehicles
SAE J1889:	LED signal and marking lighting devices
SAE J1849:	Emergency Vehicle Sirens
SAE J1690:	Flashers
SAE J578:	Color specification
SAEJ575:	Test methods and equipment for lighting devices for use on vehicles less than 2032mm in overall width
SAE J2498:	Minimum performance of the warning light system use on emergency vehicles
SAE J2139:	Tests for signal and marking devices use on vehicles 2032mm or more in overall width

SAE J595 and J845

Photometric Class Ratings

Class 1 - Authorized Emergency Vehicles responding to emergency situations.

Class 2 - Authorized maintenance or service vehicles to warn of traffic hazards.

Class 3 - Vehicles authorized to display an optical warning device for identification only.

Summary

Sirens and emergency vehicle lights work together to maximize early detection, recognition and response to an oncoming emergency vehicle. Sirens will often provide the earliest detection in urban environments while the lighting system provides improved ability to locate the emergency vehicle.

Manufacturers, emergency workers and emergency departments have worked together over the years to create standards and guidelines that help to ensure proper performance and use of emergency signals.

When combined with proper training, these standards and guidelines can reduce emergency response times while maximizing the safety of the first responders and other public safety personnel.

Appendix – Additional Information

Federal Signal Corporation (NYSE: FSS) is a leader in advancing security and well-being for communities and workplaces. The company designs and manufactures a suite of products and integrated solutions for municipal, governmental, educational, industrial and airport customers. Federal Signal was founded in 1901.

Federal Signal's Safety & Security Systems group is the driving force behind technology that provides safe and reliable emergency warning for first responders. It is our commitment to engineer the most reliable and high-performing products for your emergency vehicle.

Vision SLR

Valor

In addition to a full line of audible and visual warning products, Federal Signal offers two non-linear, V-shaped lightbar platforms that provide more light output at the critical intersection angles. In addition, these two LED lightbars offer multicolor capability to change color combinations from blue to red and a dimming feature to adjust light intensity. Exclusive to Federal Signal, the following technologies are built-into our products to increase the efficiency of your vehicle's lighting system:

Solaris®
Federal Signal's Solaris® LED reflector design is engineered to significantly increase off-axis warning. The high-efficiency Solaris reflector maximizes the LED light source to eliminate dark spots and distribute 360-degrees of light coverage.

ROC (Reliable Onboard Circuitry™)
Federal Signal introduced a breakthrough in lightbar construction with the revolutionary ROC (Reliable Onboard Circuitry™) technology. ROC is manufactured to eliminate approximately 85% of the connection failure points found in a typical lightbar assembly. Wires, connections and assemblies have been replaced by PCB assemblies — reducing labor repair time and increasing the road time for emergency vehicles.

SpectraLux™
Exclusive to Federal Signal, SpectraLux™ multicolor LED technology provides the ability for a lighthead to change color while in operation. Indivdiual lightheads can change between Red, Blue, Amber or White.

Solaris® SLR
Federal Signal's Solaris® SLR design significantly maximizes the LED light source for full light coverage. SLR rotators in the Vision SLR, provide rotating, oscillating, flashing and flood lighting functionality.

FS Convergence Network
The FS Convergence Network provides "plug-n-play" installation from Federal Signal's SmartSiren® Platinum, amplifier and controller, to our family of serial communication lightbars and the Solaris ILS Interior Lighting System (ILS).

For more information on Federal Signal's audible and visual warning products, visit http://www.fedsig.com

Resource Information:

National Law Enforcement Officers Memorial Fund, *Alarming Rise in 2010 Law Enforcement Officer Fatalities* http://www.nleomf.org/newsroom/news-releases/alarming-rise-in-2010-law.html

U.S. Department of Justice, Federal Bureau of Investigation, *Law Enforcement Officers Killed and Assaulted 2002* http://www.fbi.gov/about-us/cjis/ucr/leoka/2002 (page 57)

Department of Justice, Federal Bureau of Investigation, *Law Enforcement Officers Accidentally Killed & Assaulted 2008* http://www2.fbi.gov/ucr/killed/2008/accidentallykilled.html

National Institute of Justice, *Keeping Officers Safe on the Road*, Beth Pearsall, NIJ Journal, issue number 265 http://www.nij.gov/journals/265/officers.htm

National Law Enforcement and Corrections Technology Center, a program of the National Institute of Justice, Summer/Fall, 2007, TECH beat, *In the Best Light*
www.justnet.org/TechBeat%20Files/IntheBestLight.pdf

International Association of Chiefs of Police, *Solutions for Safer Traffic Stops*, Richard J. Ashton,
The Police Chief Magazine, April 2011
http://policechiefmagazine.org/magazine/index.cfm?fuseaction=display&article_id=331&issue_id=72004

University of Michigan Transportation Research Institute, *Inferences About Emergency Vehicle Warning Lighting Systems from Crash Data*, Flannagan, M.J. & Blower, D.F. (2005)
www.ncjrs.gov/pdffiles1/nij/231358.pdf

University of Michigan Transportation Research Institute, *Effects of Warning Lamps on Pedestrian Visibility and Driver Behavior,* Flannagan, M.J. & Devonshire, J.M. (2007)
www.sae.org/standardsdev/tsb/cooperative/nblighting.pdf

University of Michigan Transportation Research Institute, *Effects of Warning Lamp Color and Intensity On Driver Vision,* Flannagan, M.J., Blower, D.F., and Devonshire, J.M. (2008)
www.sae.org/standardsdev/tsb/cooperative/warninglamp0810.pdf

FEMA, U.S. Department of Homeland Security and U.S. Fire Administration, *Emergency Vehicle Visibility and Conspicuity Study,* FA-323/August 2009
http://www.usfa.fema.gov/downloads/pdf/publications/fa_323.pdf

This information is a service of Federal Signal Corporation, the world leader in emergency vehicle warning systems.