Light Emitting Diodes

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Introduction

This brief introduction and discussion of light emitting diode characteristics is adapted from a variety of manufacturer data sheets and application notes. The student should refer to these for detailed information.

Overview of Light Emitting Diodes

Light emitting diodes, commonly referred to as LEDs, are semiconductor diodes that emit light in proportion to a forward bias current. Common semiconductor materials used are Gallium Arsenide Phosphide and Gallium Phosphide. The wavelength band emitted is determined by the mix of the different elements. Common colors include red, orange, yellow, green, blue, and white. The spectral bandwidths are medium narrow and include enough of the spectrum of adjacent colors to make the displayed color noticeably impure. Blue LEDs generally have a wider bandwidth and a degree of white is noticeable. White LEDs are blue LEDs that includes a broad spectrum yellow phosphor excited by blue light. Yellow and blue add to make white light. These typically have a peak spectral response in the blue region and appear as bluish white. Because the spectrum has sharp peaks the white light has a subjective harsh character.

Some diodes are made to emit in the infrared band. These are commonly referred to as infrared LEDs. Although, technically, since infrared is not visible, it is not properly referred to as light. The correct terminology is infrared emitting diodes (IRED).

The following chart shows typical LED characteristics. Note that the wavelength for high efficiency red is shorter than for standard red and is thus higher on the human eye spectral sensitivity curve and appears significantly brighter for the same radiated power. Note that although green LEDs are much less efficient than red LEDs, the human eye is much more sensitive to green than red and thus green LEDs appear nearly as bright as red LEDs for the same forward current. Note: this chart is old and newer parts in the yellow-white range are significantly more efficient – table will be updated in the future.

Color	**Typical Peak Wavelength**	**Rough radiated mW/mA**	**Forward Voltage @ 10 mA**	**Rough efficiency @ 10 mA**
Infrared	950 nm	0.0800	1.2	6.7 %
Red	660 nm	0.0090	1.6	0.6
High efficiency Red	626 nm	0.0040	2.2	0.2
Orange	608 nm	0.0008	2.2	0.04
Yellow	585 nm	0.0008	2.2	0.04
Green	560 nm	0.0005	2.3	0.02
Blue	430 nm	0.0500	3.5	1.4
White	blue + yellow	0.0500	3.5	1.4

Light Emitting Diodes

Of the conventional LEDs, red LEDs are the most common and generally the brightest. Orange LEDs are noticeably dimmer than red LEDs. The quality of orange is generally not very good and some people might mistake them for red. Yellow or amber LEDs are generally the dimmest of all the colors. It is difficult to find yellow LEDs that can produce the brightness of red or green. Many green LEDs have a yellowish character to them. Some of the newer green LEDs (typically called super green or ultra green) are made with a modified blue LED process and produce a very good green light and are also much more efficient than traditional green LEDs. Note that the efficiency of white LEDs is comparable to that of fluorescent lights. Because of the much longer life of white LEDs, small incandescent light bulbs in instruments will soon be replaced with white LEDs. Small flashlights are already available that use white LEDs.

Newer technology in LEDs changes the discussion about green and yellow LEDs in the above paragraph. The newer green and amber LEDs have a narrower bandwidth and are considerably more efficient. This new class of LEDs is now replacing the incandescent lamps in traffic signals.

The effective viewing angle of an LED is determined by the built-in lens and can range from very narrow (only a few degrees) to very wide (more than 100 degrees). The narrow angle devices appear very bright, but only from a limited perspective. The wide angle devices appear much dimmer but can be seen from many angles. The total power radiated is about the same for each. When comparing the brightness of different LEDs in a catalog, the viewing angle must be considered. Wide angle devices will have very poor brightness specs compared to narrow angle devices – that is not a fair comparison. Both may be the same part – only the lens is different. Wide and narrow angle devices are made for different purposes. You must know your purpose and pick from LEDs with the appropriate viewing angle.

Common Packages

LED's are made in a variety of packages. The two most common styles are known as T-1 (3 mm diameter) and T-1 ¾ (5 mm diameter). In these packages, the LED element is mounted on a small reflector (to redirect light that would otherwise go out the rear of the part) inside a transparent epoxy case. The epoxy also forms a lens to direct the light forward. The lens also controls the beam width and LEDs are available with beam widths that range from only a few degrees to over 100 degrees. There are four different styles of this case.

Clear: This style is used when it is desired for the LED to resemble a point source of light. In this case, the lens system may be designed to produce a wide viewing angle. Another usage for this style is when the maximum possible brightness is desired since the package losses are minimized. LEDs known as super-bright or ultra-bright are only available in this style. Often the beam width is very narrow. This style is commonly used in signs or annunciator panels where the light must be readily seen, even in daylight. When driven by 20 mA, super-bright LEDs are often painfully bright to view head-on at close range.

Diffused: Glass particles are added to the epoxy to diffuse the light so that it appears more as a pleasing area source rather than a harsh point source. A common application of these LEDs is in instrument panels. The diffusing process reduces the radiated power somewhat but that is generally of no concern since the quality of appearance is greatly improved.

Tinted and clear: The primary purpose of tinting the LED with the color it will shine is so a user can know what the color will be when the LED is on. Tinting generally does not alter the wavelength band emitted although an embedded optical bandpass filter can improve the color quality of blue and green LEDs. Tinting causes a loss of radiated power but that is generally of no concern.

Tinted and diffused: This is the most popular style for instrument displays since it has all the advantages of diffusion and tinting. These are the best looking LED's.

Multi-color LEDs

It is possible to combine different color LEDs into the same package with separate or shared leads. Red and green are often combined. Green and amber is another combination. There are also packages that combine red, green, and blue. These parts are generally used with only a single LED lit at any time and have the advantage of simplifying a panel display.

By applying different currents to the different LEDs, an effective color interpolated between the LED colors can be produced. This is a visual effect only – light wavelengths are not being varied. Because the LED elements are mounted side by side they emit light at different angles about the common LED axis. Thus, if more than one LED is lit, the effective color seen will depend on the particular viewing angle. A red/green LED is normally used as either a red or green LED at any given time. Attempting to make yellow by turning both on does work except that the effective color can vary from near red through yellow to near green depending on the viewing angle unless a very good diffusion filter is used.

Usage of LEDs

It is extremely important to understand that LEDs are current operated devices – they put out light in proportion to applied forward current. At low currents, the output power is a very linear function of forward current. At higher currents the proportionality factor becomes less and there is a final saturation level. If a voltage is forced across an LED, the result will be excessive current and rapid destruction of the device. LEDs are normally operated at forward currents between about 2 and 20 milliamperes. High power devices might be operated at currents exceeding 100 milliamperes. Sometimes pulse currents in excess of 1 Ampere are used. LEDs will not operate in the reverse bias mode and generally should not be forced to conduct reverse current – some LEDs may suffer damage as a result.

The current through an LED is generally set by an appropriate resistance in series with the LED and a voltage source. The resistor value is calculated as follows:

$$R_{series} = \frac{V_A - V_F}{I_{desired}}$$

(rounded up or down to a convenient standard resistor value)

where:
R_{series} is the resistance to put in series with the LED and applied voltage
V_A is the applied voltage
V_F is the forward voltage drop of the LED at the desired forward current
$I_{desired}$ is the desired forward current

Laser Diodes

Laser (Light Amplification by Stimulated Emission of Radiation) diodes have become very popular in a number of applications. A laser diode is similar to a conventional LED except that above a certain operating current, the light spectrum emitted becomes very narrow (practically monochromatic) and the output power increases at a higher slope with applied current. A lens is used to form the light into a thin beam that has low divergence. Thus, the reflected spot is visible a considerable distance away. The laser region is very narrow and is very close to the burn-out point. Thus, the current through a laser diode has to be carefully controlled and it is common to purchase a laser diode assembly with a built-in control circuit and lens.

There are two basic types of laser diodes used for laser pointers and such. The difference is in the wavelength emitted. The long wave (650 nm) is the most common since it is lower cost. The short wave (635 nm) is advertised as much brighter but costs more. Both emit about the same power but because the human eye is more sensitive at 635 nm than at 650 nm, the spot appears significantly brighter. Although it does not appear as bright in comparison, a 650 nm laser is just as dangerous as a 635 nm laser if improperly used. Damage is damage whether the eye can see it or not.

The primary danger to eyes from any kind of laser is not the narrow spectrum emitted (although that is a factor in some situations) but that a lens is used to form a narrow beam. Thus, when a laser beam is directed into an eye, the eye receives all the power emitted as no dispersion occurs. It takes remarkably little power to do damage. The light output of a typical diode used in laser pointers and in some toys is around 3 mW. This seems like a small power. Consider that this power is confined to a circle about 5 mm in diameter. The power density is then:

$$P_d = \frac{0.003}{(3.14 * 0.005^2)/4} = 153 \text{ Watts/meter}^2 \text{ !!!}$$

As a point of reference, the total power over the visible spectrum from the sun at noon is about 1000 Watts/meter^2. Thus, a laser diode should never be pointed at someone's eye. Children (or immature adults, a.k.a. morons) should never operate a laser device as eye damage could occur to themselves or people nearby. Cats love to chase a moving laser spot and a market has developed to sell laser diode devices as cat toys. These are fine if properly used. I use a conventional laser pointer with my cats and they have lots of fun. It is very important not to shine the light into the cat's eyes. Just because a person is ignorant of the consequences does not mean that the consequences do not occur.