

The Light Emitting Diode

Light Emitting Diodes or **LED's**, are among the most widely used of all the different types of semiconductor diodes available today and are commonly used in TV's and colour displays.

They are the most visible type of diode, that emit a fairly narrow bandwidth of either visible light at different coloured wavelengths, invisible infra-red light for remote controls or laser type light when a forward current is passed through them.

The “**Light Emitting Diode**” or **LED** as it is more commonly called, is basically just a specialised type of diode as they have very similar electrical characteristics to a PN junction diode. This means that an LED will pass current in its forward direction but block the flow of current in the reverse direction.

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Light emitting diodes are made from a very thin layer of fairly heavily doped semiconductor material and depending on the semiconductor material used and the amount of doping, when forward biased an LED will emit a coloured light at a particular spectral wavelength.

When the diode is forward biased, electrons from the semiconductors conduction band recombine with holes from the valence band releasing sufficient energy to produce photons which emit a monochromatic (single colour) of light. Because of this thin layer a reasonable number of these photons can leave the junction and radiate away producing a coloured light output.

Then we can say that when operated in a forward biased direction **Light Emitting Diodes** are semiconductor devices that convert electrical energy into light energy.

The construction of a Light Emitting Diode is very different from that of a normal signal diode. The PN junction of an LED is surrounded by a transparent, hard plastic epoxy resin hemispherical shaped shell or body which protects the LED from both vibration and shock.

Surprisingly, an LED junction does not actually emit that much light so the epoxy resin body is constructed in such a way that the photons of light emitted by the junction are reflected away from the surrounding substrate base to which the diode is attached and are focused upwards through the domed top of the LED, which itself acts like a lens concentrating the amount of light. This is why the emitted light appears to be brightest at the top of the LED.

However, not all LEDs are made with a hemispherical shaped dome for their epoxy shell. Some indication LEDs have a rectangular or cylindrical shaped construction that has a flat surface on top or their body is shaped into a bar or arrow. Generally, all LED’s are manufactured with two legs protruding from the bottom of the body.

Also, nearly all modern light emitting diodes have their cathode, (–) terminal identified by either a notch or flat spot on the body or by the cathode lead being shorter than the other as the anode (+) lead is longer than the cathode (k).

Unlike normal incandescent lamps and bulbs which generate large amounts of heat when illuminated, the light emitting diode produces a “cold” generation of light which leads to high efficiencies than the normal “light bulb” because most of the generated energy radiates away within the visible spectrum. Because LEDs are solid-state devices, they can be extremely small and durable and provide much longer lamp life than normal light sources.



LED Construction

Light Emitting Diode Colours

So how does a light emitting diode get its colour. Unlike normal signal diodes which are made for detection or power rectification, and which are made from either Germanium or Silicon semiconductor materials, **Light Emitting Diodes** are made from exotic semiconductor compounds such as Gallium Arsenide (GaAs), Gallium Phosphide (GaP), Gallium Arsenide Phosphide (GaAsP), Silicon Carbide (SiC) or Gallium Indium Nitride (GaInN) all mixed together at different ratios to produce a distinct wavelength of colour.

Different LED compounds emit light in specific regions of the visible light spectrum and therefore produce different intensity levels. The exact choice of the semiconductor material used will determine the overall wavelength of the photon light emissions and therefore the resulting colour of the light emitted.

Light Emitting Diode Colours

| Typical LED Characteristics | | | |
|-----------------------------|------------|--------|-----------------------|
| Semiconductor Material | Wavelength | Colour | V _F @ 20mA |

| | | | |
|---------|-----------|-----------|------|
| GaAs | 850-940nm | Infra-Red | 1.2v |
| GaAsP | 630-660nm | Red | 1.8v |
| GaAsP | 605-620nm | Amber | 2.0v |
| GaAsP:N | 585-595nm | Yellow | 2.2v |
| AlGaP | 550-570nm | Green | 3.5v |
| SiC | 430-505nm | Blue | 3.6v |
| GaInN | 450nm | White | 4.0v |

Thus, the actual colour of a light emitting diode is determined by the wavelength of the light emitted, which in turn is determined by the actual semiconductor compound used in forming the PN junction during manufacture.

Therefore the colour of the light emitted by an LED is NOT determined by the colouring of the LED's plastic body although these are slightly coloured to both enhance the light output and to indicate its colour when its not being illuminated by an electrical supply.

Light emitting diodes are available in a wide range of colours with the most common being RED, AMBER, YELLOW and GREEN and are thus widely used as visual indicators and as moving light displays.

Recently developed blue and white coloured LEDs are also available but these tend to be much more expensive than the normal standard colours due to the production costs of mixing together two or more complementary colours at an exact ratio within the semiconductor compound and also by injecting nitrogen atoms into the crystal structure during the doping process.

From the table above we can see that the main P-type dopant used in the manufacture of **Light Emitting Diodes** is Gallium (Ga, atomic number 31) and that the main N-type dopant used is Arsenic (As, atomic number 33) giving the resulting compound of Gallium Arsenide (GaAs) crystalline structure.

The problem with using Gallium Arsenide on its own as the semiconductor compound is that it radiates large amounts of low brightness infra-red radiation (850nm-940nm approx.) from its junction when a forward current is flowing through it.

The amount of infra-red light it produces is okay for television remote controls but not very useful if we want to use the LED as an indicating light. But by adding Phosphorus (P, atomic number 15), as a third dopant the overall wavelength of the emitted radiation is reduced to below 680nm giving visible red light to the human eye. Further refinements in the doping process of the PN junction have resulted in a range of colours spanning the spectrum of visible light as we have seen above as well as infra-red and ultra-violet wavelengths.

By mixing together a variety of semiconductor, metal and gas compounds the following list of LEDs can be produced.

Related Products: LED Displays Segmented | LED Modules

Types of Light Emitting Diode

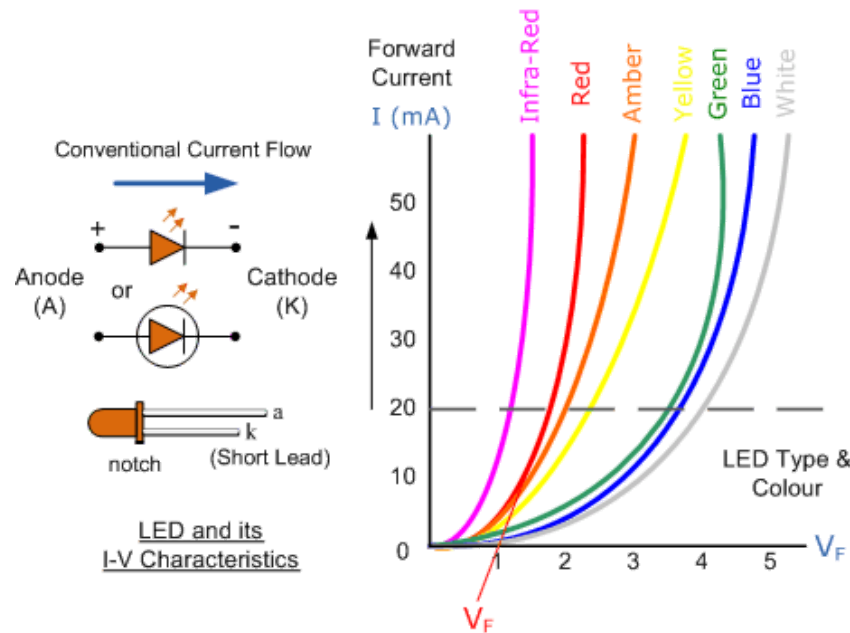
- Gallium Arsenide (GaAs) – infra-red
- Gallium Arsenide Phosphide (GaAsP) – red to infra-red, orange
- Aluminium Gallium Arsenide Phosphide (AlGaAsP) – high-brightness red, orange-red, orange, and yellow
- Gallium Phosphide (GaP) – red, yellow and green
- Aluminium Gallium Phosphide (AlGaP) – green
- Gallium Nitride (GaN) – green, emerald green
- Gallium Indium Nitride (GaInN) – near ultraviolet, bluish-green and blue
- Silicon Carbide (SiC) – blue as a substrate
- Zinc Selenide (ZnSe) – blue
- Aluminium Gallium Nitride (AlGaN) – ultraviolet

Like conventional PN junction diodes, light emitting diodes are current-dependent devices with its forward voltage drop V_F , depending on the semiconductor compound (its light colour) and on the forward biased LED current. Most common LED's require a forward operating voltage of between approximately 1.2 to 3.6 volts with a forward current rating of about 10 to 30 mA, with 12 to 20 mA being the most common range.

Both the forward operating voltage and forward current vary depending on the semiconductor material used but the point where conduction begins and light is produced is about 1.2V for a standard red LED to about 3.6V for a blue LED.

The exact voltage drop will of course depend on the manufacturer because of the different dopant materials and wavelengths used. The voltage drop across the LED at a particular current value, for example 20mA, will also depend on the initial conduction V_F point. As an LED is effectively a diode, its forward current to voltage characteristics curves can be plotted for each diode colour as shown below.

Light Emitting Diodes I-V Characteristics.



Light Emitting Diode (LED) Schematic symbol and I-V Characteristics Curves showing the different colours available.

Before a light emitting diode can “emit” any form of light it needs a current to flow through it, as it is a current dependant device with their light output intensity being directly proportional to the forward current flowing through the LED.

As the LED is to be connected in a forward bias condition across a power supply it should be *current limited* using a series resistor to protect it from excessive current flow. Never connect an LED directly to a battery or power supply as it will be destroyed almost instantly because too much current will pass through and burn it out.

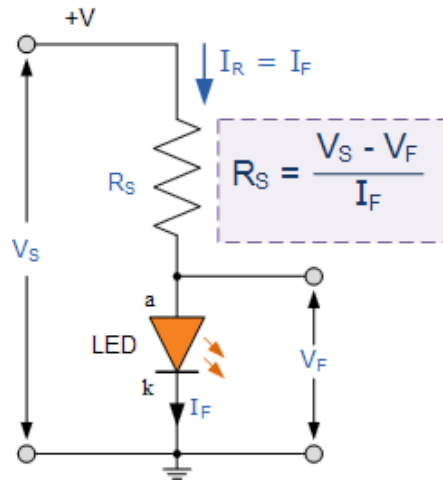
From the table above we can see that each LED has its own forward voltage drop across the PN junction and this parameter which is determined by the semiconductor material used, is the forward voltage drop for a specified amount of forward conduction current, typically for a forward current of 20mA.

In most cases LEDs are operated from a low voltage DC supply, with a series resistor, R_S used to limit the forward current to a safe value from say 5mA for a simple LED indicator to 30mA or more where a high brightness light output is needed.

LED Series Resistance.

The series resistor value R_S is calculated by simply using **Ohm's Law**, by knowing the required forward current I_F of the LED, the supply voltage V_S across the combination and the expected forward voltage drop of the LED, V_F at the required current level, the current limiting resistor is calculated as:

LED Series Resistor Circuit



Light Emitting Diode Example No1

An amber coloured LED with a forward volt drop of 2 volts is to be connected to a 5.0v stabilised DC power supply. Using the circuit above calculate the value of the series resistor required to limit the forward current to less than 10mA. Also calculate the current flowing through the diode if a 100 Ω series resistor is used instead of the calculated first.

1). series resistor required at 10mA.

$$R_S = \frac{V_S - V_F}{I_F} = \frac{5\text{v} - 2\text{v}}{10\text{mA}} = \frac{3}{10 \times 10^{-3}} = 300\Omega$$

2). with a 100 Ω series resistor.

$$R_S = \frac{V_S - V_F}{I_F}$$

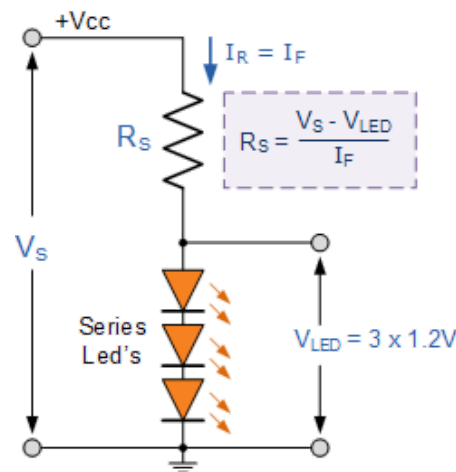
$$\therefore I_F = \frac{V_S - V_F}{R_S} = \frac{5 - 2}{100} = 30\text{mA}$$

We remember from the **Resistors** tutorials, that resistors come in standard preferred values. Our first calculation above shows that to limit the current flowing through the LED to 10mA exactly, we would require a 300Ω resistor. In the E12 series of resistors there is no 300Ω resistor so we would need to choose the next highest value, which is 330Ω. A quick re-calculation shows the new forward current value is now 9.1mA, and this is ok.

Connecting LEDs Together in Series

We can connect LED's together in series to increase the number required or to increase the light level when used in displays. As with series resistors, LED's connected in series all have the same forward current, I_F flowing through them as just one. As all the LEDs connected in series pass the same current it is generally best if they are all of the same colour or type.

LED's in Series



Although the LED series chain has the same current flowing through it, the series voltage drop across them needs to be considered when calculating the required resistance of the current limiting resistor, R_S . If we assume that each LED has a voltage drop across it when illuminated of 1.2 volts, then the voltage drop across all three will be $3 \times 1.2\text{v} = 3.6\text{ volts}$.

If we also assume that the three LEDs are to be illuminated from the same 5 volt logic device or supply with a forward current of about 10mA, the same as above. Then the voltage drop across the resistor, R_S and its resistance value will be calculated as:

$$V_{\text{LED}} = 3 \times 1.2\text{volts} = 3 \times 1.2\text{v} = 3.6\text{v}$$

$$R_S = V_S - V_{\text{LED}} = 5 - 3.6 = 1.4\text{volts}$$

$$\therefore R_S = \frac{1.4\text{v}}{10\text{mA}} = 140\Omega$$

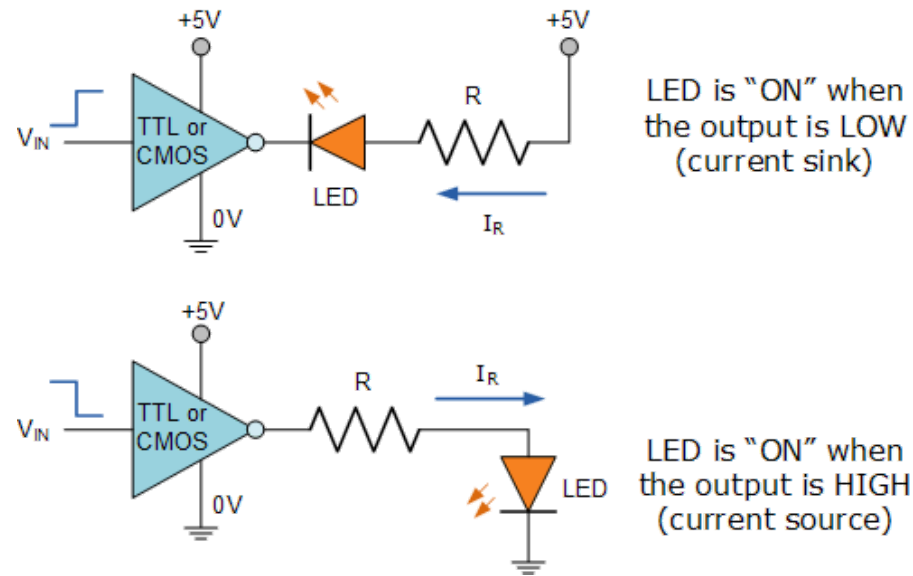
Again, in the E12 (10% tolerance) series of resistors there is no 140Ω resistor so we would need to choose the next highest value, which is 150Ω .

LED Driver Circuits

Now that we know what is an LED, we need some way of controlling it by switching it “ON” and “OFF”. The output stages of both TTL and CMOS logic gates can both source and sink useful amounts of current therefore can be used to drive an LED. Normal integrated circuits (ICs) have an output drive current of up to 50mA in the sink mode configuration, but have an internally limited output current of about 30mA in the source mode configuration.

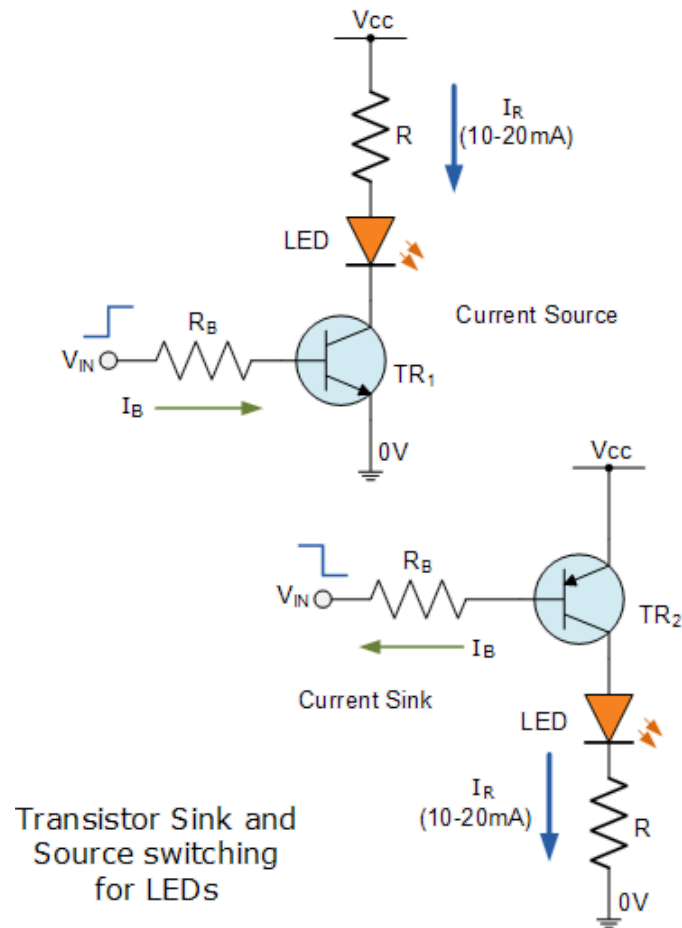
Either way the LED current must be limited to a safe value using a series resistor as we have already seen. Below are some examples of driving light emitting diodes using inverting ICs but the idea is the same for any type of integrated circuit output whether combinational or sequential.

IC Driver Circuit



If more than one LED requires driving at the same time, such as in large LED arrays, or the load current is too high for the integrated circuit or we may just want to use discrete components instead of ICs, then an alternative way of driving the LEDs using either bipolar NPN or PNP **transistors as switches** is given below. Again as before, a series resistor, R_S is required to limit the LED current.

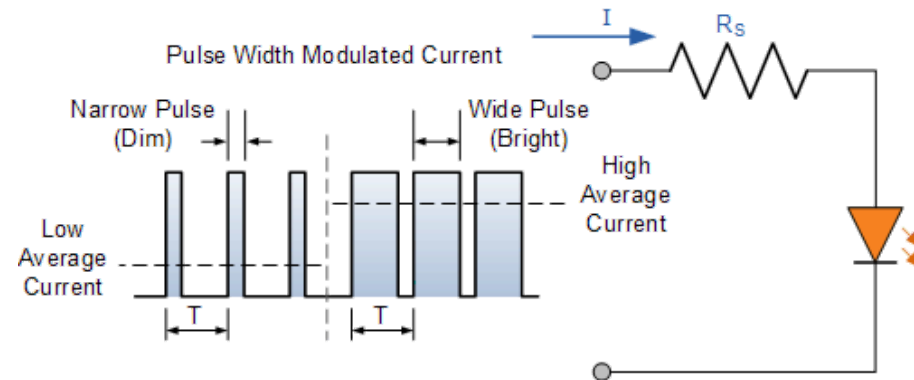
Transistor Driver Circuit



The brightness of a light emitting diode cannot be controlled by simply varying the current flowing through it. Allowing more current to flow through the LED will make it glow brighter but will also cause it to dissipate more heat. LEDs are designed to produce a set amount of light operating at a specific forward current ranging from about 10 to 20mA.

In situations where power savings are important, less current may be possible. However, reducing the current to below say 5mA may dim its light output too much or even turn the LED "OFF" completely. A much better way to control the brightness of LEDs is to use a control process known as "Pulse Width Modulation" or PWM, in which the LED is repeatedly turned "ON" and "OFF" at varying frequencies depending upon the required light intensity of the LED.

LED Light Intensity using PWM



When higher light outputs are required, a pulse width modulated current with a fairly short duty cycle (“ON-OFF” Ratio) allows the diode current and therefore the output light intensity to be increased significantly during the actual pulses, while still keeping the LEDs “average current level” and power dissipation within safe limits.

This “ON-OFF” flashing condition does not affect what is seen by the human eye as it “fills” in the gaps between the “ON” and “OFF” light pulses, providing the pulse frequency is high enough, making it appear as a continuous light output. So pulses at a frequency of 100Hz or more actually appear brighter to the eye than a continuous light of the same average intensity.

Multi-coloured Light Emitting Diode

LEDs are available in a wide range of shapes, colours and various sizes with different light output intensities available, with the most common (and cheapest to produce) being the standard 5mm Red Gallium Arsenide Phosphide (GaAsP) LED.

LED’s are also available in various “packages” arranged to produce both letters and numbers with the most common being that of the “seven segment display” arrangement.

Nowadays, full colour flat screen LED displays, hand held devices and TV’s are available which use a vast number of multicoloured LED’s all been driven directly by their own dedicated IC.

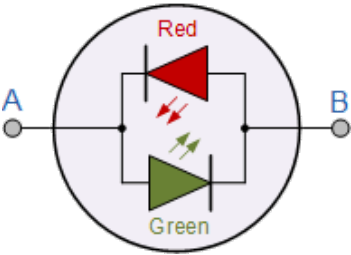
Most light emitting diodes produce just a single output of coloured light however, multi-coloured LEDs are now available that can produce a range of different colours from within a single device. Most of these are actually two or three LEDs fabricated within a single package.

Bicolour Light Emitting Diodes

A bicolour light emitting diode has two LEDs chips connected together in “inverse parallel” (one forwards, one backwards) combined in one single package. Bicolour LEDs can produce any one of three colours for example, a red colour is emitted when the device is connected with current flowing in one direction and a green colour is emitted when it is biased in the other direction.

This type of bi-directional arrangement is useful for giving polarity indication, for example, the correct connection of batteries or power supplies etc. Also, a bi-directional current produces both colours mixed together as the two LEDs would take it in turn to illuminate if the device was connected (via a suitable resistor) to a low voltage, low frequency AC supply.

A Bicolour LED



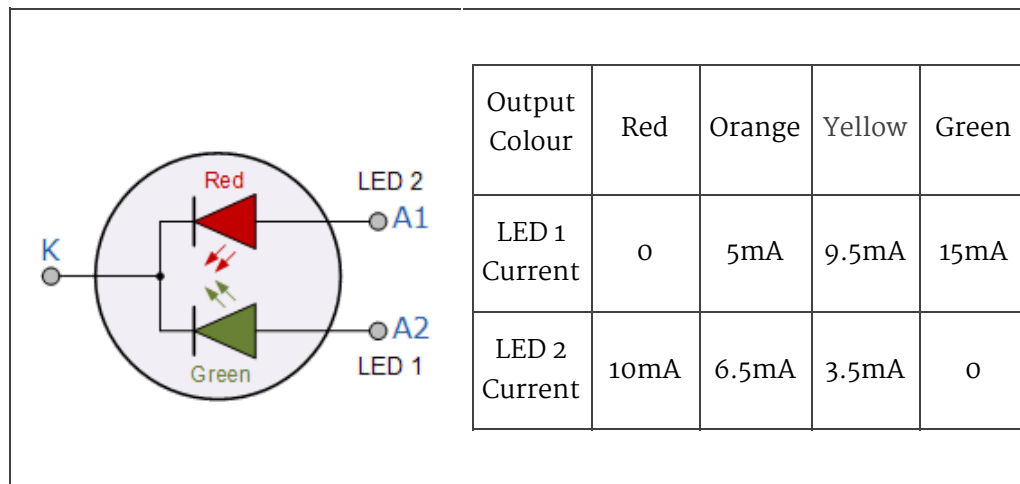
| LED Selected | Terminal A | | AC |
|--------------|------------|-----|--------|
| | + | – | |
| LED 1 | ON | OFF | ON |
| LED 2 | OFF | ON | ON |
| Colour | Green | Red | Yellow |

Tricoloured Light Emitting Diode

The most popular type of tricolour light emitting diode comprises of a single Red and a Green LED combined in one package with their cathode terminals connected together producing a three terminal device. They are called tricolour LEDs because they can give out a single red or a green colour by turning “ON” only one LED at a time.

These tricoloured LED’s can also generate additional shades of their primary colours (the third colour) such as Orange or Yellow by turning “ON” the two LEDs in different ratios of forward current as shown in the table thereby generating 4 different colours from just two diode junctions.

A Multi or Tricoloured LED



LED Displays

As well as individual colour or multi-colour LEDs, several light emitting diodes can be combined together within a single package to produce displays such as bargraphs, strips, arrays and seven segment displays.

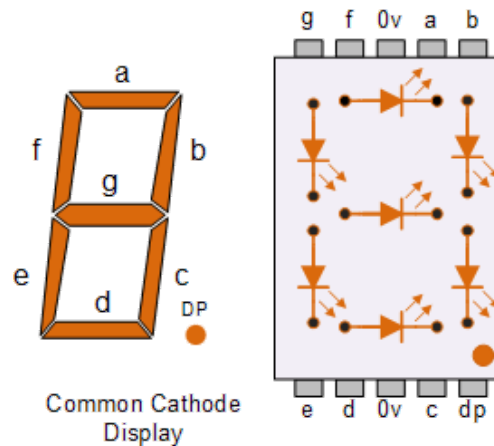
A **7-segment LED display** provides a very convenient way when decoded properly of displaying information or digital data in the form of numbers, letters or even alpha-numerical characters and as their name suggests, they consist of seven individual LEDs (the segments), within one single display package.

In order to produce the required numbers or characters from 0 to 9 and A to F respectively, on the display the correct combination of LED segments need to be illuminated. A standard seven segment LED display generally has eight input connections, one for each LED segment and one that acts as a common terminal or connection for all the internal segments.

The Common Cathode Display (CCD) – In the common cathode display, all the cathode connections of the LEDs are joined together and the individual segments are illuminated by application of a HIGH, logic “1” signal.

The Common Anode Display (CAD) – In the common anode display, all the anode connections of the LEDs are joined together and the individual segments are illuminated by connecting the terminals to a LOW, logic “0” signal.

A Typical Seven Segment LED Display

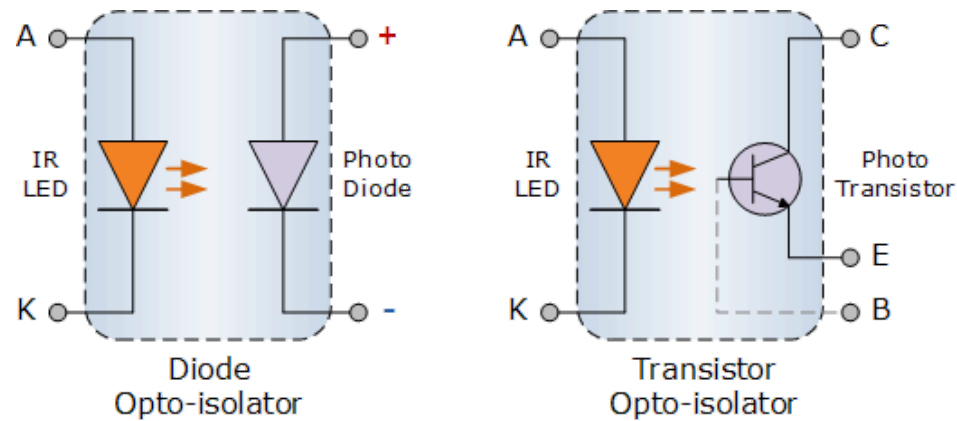


Opto-coupler

Finally, another useful application of light emitting diodes is **Opto-coupling**. An opto-coupler or opto-isolator as it is also called, is a single electronic device that consists of a light emitting diode combined with either a photo-diode, photo-transistor or photo-triac to provide an optical signal path between an input connection and an output connection while maintaining electrical isolation between two circuits.

An opto-isolator consists of a light proof plastic body that has a typical breakdown voltages between the input (photo-diode) and the output (photo-transistor) circuit of up to 5000 volts. This electrical isolation is especially useful where the signal from a low voltage circuit such as a battery powered circuit, computer or microcontroller, is required to operate or control another external circuit operating at a potentially dangerous mains voltage.

Photo-diode and Photo-transistor Opto-couplers



The two components used in an opto-isolator, an optical transmitter such as an infra-red emitting Gallium Arsenide LED and an optical receiver such as a photo-transistor are closely optically coupled and use light to send signals and/or information between its input and output. This allows information to be transferred between circuits without an electrical connection or common ground potential.

Opto-isolators are digital or switching devices, so they transfer either “ON-OFF” control signals or digital data. Analogue signals can be transferred by means of frequency or pulse-width modulation.

38 Comments

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SUBMIT

w william

Can LEDs be made to emit UVA, UVB, or UVC ?

Posted on October 26th 2016 | 2:31 am

← Reply



Wayne Storr

Ultraviolet and purple coloured LED's with low wavelengths are commonly available as they are used for the quick drying of inks, sterilisation of water, etc

Posted on October 26th 2016 | 1:39 pm

← Reply

E Ego

“So pulses at a frequency of 100Hz or more actually appear brighter to the eye than a continuous light of the same average intensity.” This statement is clearly wrong!

M Mark

I used to work on infra red fibre optic transmission systems in the 70s and didn't realise that the different coloured LEDS had such different forward voltages.

A very good tutorial on the subject – thanks.

Posted on July 28th 2016 | 5:53 am

← Reply

m masoom raza

can i operate LED on AC voltages if yes then what is the condition and what voltage will.

Posted on July 19th 2016 | 6:10 pm

← Reply



Wayne Storr

Yes you can use LED's on AC supplies, but as it's basically a diode it will only pass current for one-half of the cycle giving it half brightness.

Posted on July 19th 2016 | 6:56 pm

← Reply

a antonio

Hello Wayne,

I'm an instructor here in the Philippines and I would like to use your article for one of my laboratory activities of my students. Can I possibly include this as one of my compilations.

Thank you!

D David

Thank you very good article

Posted on May 13th 2016 | 9:17 pm

← Reply

D Daniel

Good day to you,

First of all, congrats for the new website look. Really well done !

I don't have any problem calculating the required current limiting resistor for a given led. Applying the Ohms law and the voltage divider principle, is plenty enough to get to the goal.

However, I saw an article on the net where the person is reverse biasing a rectifier diode in parallel with a regular led, then feeding that circuit through a current limiting resistor. The element that scared me the most is the fact that he's using the mains as his power source, yes the 230 VAC !!!

Doing simple calculations would lead me to a conclusion where the resistor would waste a lot of energy and dissipate way more heat that it can handle.

I clearly understand that the article I'm talking about isn't yours, but if you could take a look at it and tell me if there is something I'm missing because I really don't see how such approach can be suggested.

The URL is : <http://ledbasedcircuits.blogspot.ca/2013/02/mains-powered-led.html>

Best regards.

Posted on April 23rd 2016 | 2:13 am

← Reply



Banta

I don't know what all this means cause its very complicated..



J Jerry

Hello this is a great site Wayne. Jerry

Posted on January 19th 2016 | 9:49 pm

⬅️ Reply

More



Marco

Hi Wayne,
I was wondering which program you used to make the illustrations for this article.
Best regards,

Marco

Posted on January 06th 2016 | 1:46 pm

⬅️ Reply

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