

Optical Electronics – RGB LED and the colours of the rainbow

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Introduction

Optical Electronics is an exciting and growing field of electronics. This activity will look at Red Green Blue (RGB) Light Emitting Diodes (LED). Optical Electronics is a great way of combining both optics and electronics theory into a context for learning. This article outlines two practical student activities using RGB LEDs. It combines electronics and optical concepts that can be adapted to suit a variety of high school grades. It is also a good introduction to colour television technology and a biological understanding of the human eye and its interpretation of colour.

Light waves come in many sizes. The size of a wave is measured as its wavelength, which is the distance between any two corresponding points on successive waves, usually peak-to-peak or trough-to-trough. The wavelengths of the light humans can see range from 400 to 700 billionths of a meter (nm – nano metres, $\times 10^{-9}$ m). But the full range of wavelengths included in the definition of electromagnetic radiation extends from one billionth of a meter, as in gamma rays, to centimetres and meters, as in radio waves. Light is one small part of the electromagnetic spectrum (Ulaby 1997).

One important use of light today is communications. Television and video systems are used everyday to give us visual messages, news and entertainment. Since 1953 the number of colour has increased dramatically televisions over monochrome (black and white) televisions (Blake 2002). Considerably more information can be transmitted using colour compared to monochrome television. Colour television also requires additional hardware using three electron guns and three different phosphors for red, green and blue.

In a CRT (cathode-ray tube), phosphor is coated on the inside of the screen. When the electron beam strikes the phosphor, it makes the screen glow. In a black-and-white screen, there is one phosphor that glows white when struck. In a colour screen, there are three phosphors arranged as dots or stripes that emit red, green and blue light. There are also three electron beams to illuminate the three different colours together. Inside any TV set the tube is wrapped in coils of wires. These are called steering coils. Each electron beam is directed by the steering coils and a grid to hit a phosphor dot of the same colour (Blake 2002).

It is not necessary for a colour TV to reproduce all the colours found in the visible spectrum. Because of the way in which the eye-brain interact, it is only necessary to transmit the colours red, green and blue (Blake 2002). Some video systems transmit the red, green and blue signals on three separate conductors, this is being used in the latest home entertainment systems on large plasma screens and projectors. These

systems are called RGB video or component video systems. Most computer monitors uses this with an additional line for synchronizing information.

RGB video is not suitable for conventional television broadcasting because of the limitation of the amount of information that can be sent via radio waves (bandwidth). The signal for analogue television broadcasting is called a composite video signal. From a distance the modulated luminosity of the red, green and blue phosphors dots are interpreted by the human eye-brain to form all of the colours that we “see”.

When light enters the eye, it passes through the cornea, aqueous humor, lens and vitreous humor then ultimately it reaches the retina, which is the light-sensing structure of the eye. The retina contains two types of cells, called cones and rods. Rods handle vision in low light, and cones handle colour vision and detail. The retina has a central area that contains a high concentration of only cones, which is responsible for sharp, detailed vision, called the macula. When light contacts these two types of cells, a series of complex chemical reactions occurs, which causes the electrical charge to increase causing an electrical current along the cells. This electric impulse eventually reaches a ganglion cell, and then the optic nerve, which then travels to the brain (Bears, Connors, Paradiso 1996).

The colour that we perceive is determined by red, green and blue “cones” in our eyes and their relative activation. When all types of cones are equally active, we interpret the colour as being “white”. We can also prove that without the activity of the three cone types, that there would be no perceived colour differences. For example, on a dark night and try to distinguish the different colours of different objects. This is difficult because only the rods are activated under dim lighting conditions.

Colour blindness occurs when one or more of the cones photo pigment (the chemicals that detect the colour) types are missing. The genes for two of the three cone photo pigments, red and green, are on the X chromosome. Because males have one X chromosome and females have two X chromosomes, genetic colour vision defects occur more often in males than females. The most common defect is the confusion of shades of red and green. For more information on the human eye colour recognition system refer to *Neuroscience: Exploring the brain* (Bears, Connors, Paradiso 1996).

One way that the additive colour mixing of the human eye-brain can be investigated is by having three light sources close together. To avoid the dangerous high voltages of a CRT we can use Red, Green and Blue Light Emitting Diodes (RGB LED's)

As with standard rectifying diodes, light emitting diodes are constructed using a junction of two differently doped semiconductor materials. Doping refers to adding impurities into the silicon crystal structure (Gray, Meyer 1993).

Doping of silicon results in a material that either adds extra electrons to the material (which is then called *n-type* for the extra negative charge carriers) or creates "holes" in the material's crystal structure (which is then called *p-type* because it results in more positive charge carriers). Where the two areas meet a process of electron/hole combination occurs forming ions. For silicon this continues until a potential barrier of 0.7 volts is reached. This is called the depletion region since all the electron/holes are recombined. For silicon diodes a voltage of 0.7 volts is required for it to start to conduct (Hambley 1997).

When current is applied across the depletion region in *forward bias* (the negative terminal of the supply is connected to the N-type material and the positive to the *p*-type material) free electrons moving across a diode can fall into empty holes from the P-type layer (Henderson 1991). This involves a drop from the conduction band (free electrons) to a lower orbital (valance band – bound electrons). When the electrons fall they release energy in the form of photons (Bailey, Wright 2003).

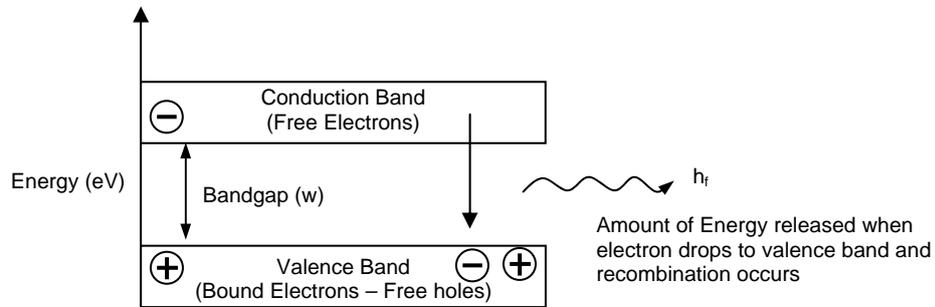


Figure 1. Bandgap determines energy emissions

Visible light-emitting diodes (VLEDs) are made of materials characterized by a wider gap between the conduction band and the lower orbital valance band. The size of the gap determines the frequency of the photon; in other words, it determines the colour of the light (Senior 1992). Standard rectifying diodes are constructed from silicon or germanium and dissipated energy through heat or non-visible photons (infrared). VLEDs are constructed of gallium arsenide or gallium phosphide and dissipate energy in the form of light and a little heat.

Semiconductor	Bandgap Energy (eV)	Wavelength (nm)
GaAsP	1.88	660 (Red)
GaAlAs	1.55 – 1.38	800 – 900 (Infra red)
GaAs	1.33	930
InGaAsP	0.95 – 0.80	1300 - 1500

Table 1. Semiconductor bandgap energies and wavelengths (Senior 1992)

LEDs have several advantages over conventional incandescent lamps. Firstly, they don't have a filament that will burn out so they last much longer. Additionally, their small plastic bulb makes them a lot more durable. They can be made quite small to fit more easily into modern electronic circuits. But the main advantage is efficiency of conversion from electrical power to optical power (Blake 2002).

Intended outcomes of this Investigation

The specific outcomes of the investigation are that student will:

- Gain an understanding of the physics behind light and semiconductors LED's.
- Develop hands on practical skills of building electronics circuits on breadboards
- Gain an understanding of the way in which the human eye-brain system perceives light.

Equipment List

- 5 volt power supply
- Philips screwdriver
- Digital multimeter

Part List

Part No.	Part	Distributor	Cat. No.	Quantity
B1	Breadboard	Dick Smith Electronics	H 4020	1
D1	RGB LED	Jaycar Electronics	ZD0270	1
R1, R2, R3	Potentiometer	Jaycar Electronics	RT-4360	3
R4, R5, R6	270 Ω $\frac{1}{4}$ W resistors	Jaycar Electronics	RR-0558	3

The following experiments are constructed on a breadboard available from Dick Smith Electronics (Cat No. H 4020). Breadboards have conductive tracks, which clip wires, running in different directions. This is shown in Figure 1.

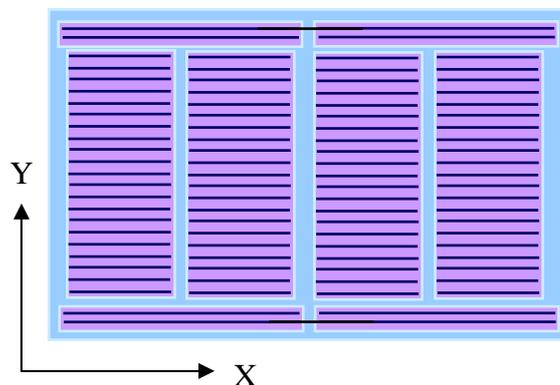


Figure 1. Breadboard conductive track layout.

In this experiment you will use an RGB LED (Red Blue Green Light Emitting Diode). This component contains red, green and blue silicon diode crystals arranged close together in a 5mm LED package. Each crystal is controlled independently and to a human observer, can be used to create all available colours of the visible spectrum.

The LED has a common cathode and three independent anodes - one for each of the three colours (see Figure 2).



Figure 2. Pin Diagram of RGB LED

LEDs are current driven devices and emit more light when the current is increased. In this exercise, three 10 k Ω potentiometers [Jaycar, cat. no. RT-4360] are used to control the intensity of each of the three colours. The voltage drop measured across the LED is used to determine the current in each LED separately.

Instructions:

- Using the breadboard, RGB LED, 270 Ω resistors and the potentiometers construct the RGB LED control circuit (see Figure 3). This is accomplished by inserting the LED into four adjacent holes to form a line of independent connections (Y axis in figure 1). Leave at least 1 hole between the leg and the edge of the group of holes.

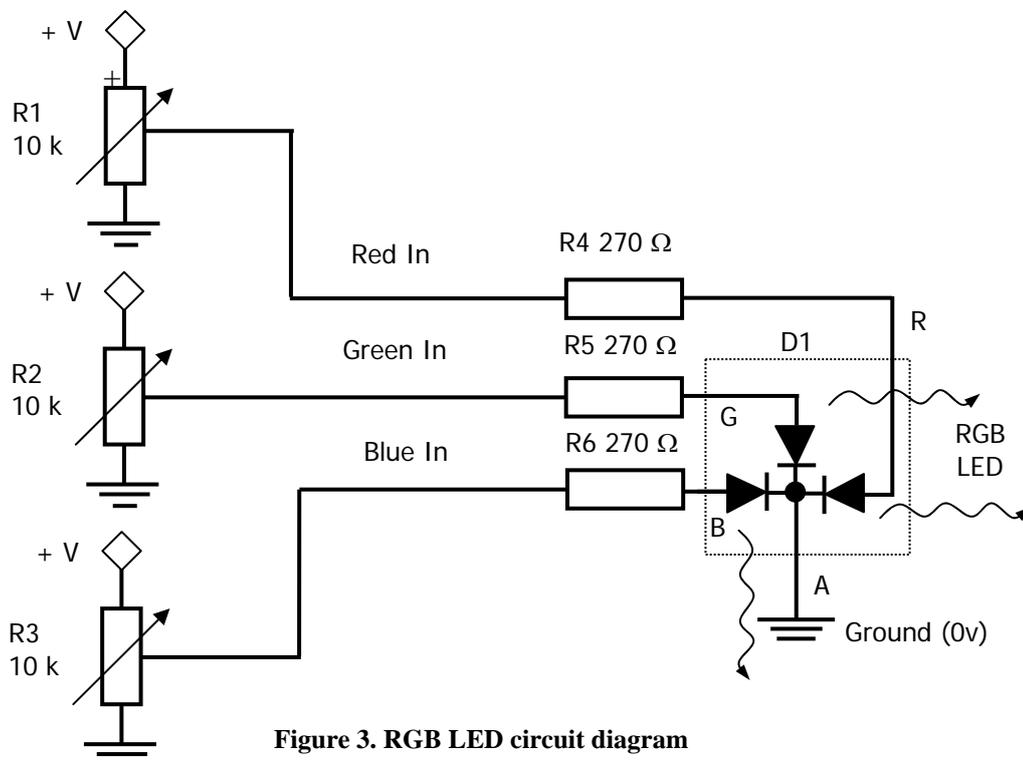


Figure 3. RGB LED circuit diagram

- Insert 3 potentiometers (pots) with two empty banks of holes between each one. Face the pins so that the single pin (wiper) is closest to the LED (see Figure 4).

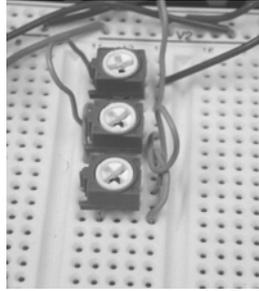


Figure 4. Placing Potentiometers

3) Using some connecting wires connect the common cathode of the LED to the Ground (0 Volts). Connect 270Ω resistors to the red, green, & blue anodes then connect short wires from the other side of the resistors to the wipers of the pots, one resistor per colour shown in Figure 5. These resistors ensure the current through the diode does not exceed the maximum allowed value.

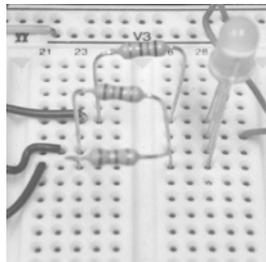


Figure 5. Placing resistors

- 4) Connect the lower pins of each of the potentiometers together and connect to 5V. Do the same for the top pins, connecting these to the ground (0V).
- 5) Test the RGB set by connecting the breadboard to a 5 volt power supply and independently adjust each of the potentiometers clockwise. Each colour should be visible in turn.

LEDs have different crystal bandgaps depending on their silicon dopants. This means that different diodes have a different threshold voltage requirement to turn the colour on.

- 6) Threshold measurements: Connect a multimeter black lead to the ground rail and red lead to the connection between the 270Ω resistor and red (top) leg of LED (Point R in Figure 3). Turn the potentiometer slowly until the red diode just begins to illuminate. Stop and record the voltage in the table then return the potentiometer so no current flows (fully anti-clockwise). Repeat this for the green and blue diodes.

Colour	Turn on voltage(v)
Red	
Green	
Blue	

Table 2. Threshold Voltages for RGB LED

7) This experiment involves setting each of the control pots at different voltages and recording the resulting colour determined by eye.

Red (v)	Green (v)	Blue (v)	Colour

Table 3. Colour Mixing Chart

From a distance the colours will tend to blend together to make different colours rather than just appearing as the separate individual colours. The eye combines the colours and so black is the absence of light and the more colour and intensity that is added the closer it becomes to white. Turn the control pots to maximum and then hold a piece of white paper over the LED. You will see white in the middle and the individual colours on the outside. The colours in the LED are mixed by the human eye colour recognition system to form the displayed colour. The colour that we perceive is determined by red, green and blue “cones” in our eyes and their relative activation. When all types of cones are equally active, we interpret the colour as being “white”. For more information on the human eye colour recognition system refer to *Neuroscience: Exploring the brain* (Bears, Connors, Paradiso 1996). Colour Images of the Additive Colour Synthesis can be found on the Practical Electronics resource page available at <http://griffithwireless.com/workshop.htm>

Colour images of the forward current and relative luminous intensity can be found on the Practical Electronics resource page. As an extension the class could be set a project to cycling through the rainbow colours continuously on a microcontroller, or setting up a light show of flashing colours. For more information on this project visit <http://griffithwireless.com/workshop.htm>

Implications of investigation

The investigation examines colour television, the electromagnetic spectrum, semiconductors, human vision and colour blindness. Students learn practical skills of building electronic circuits and are given an understand of the interaction of biological human eye systems and electronic RGB colour display systems.

Optical Electronics is an exciting and growing field of electronics. This article on RGB LEDs is a small sample of the Optical Electronics Workshop, which examines optical fibre communication, light sources, including LED's and lasers, and a brief look at the growing field of integrated optics. Optical Electronics is a great way of combining both optics and electronics theory into a context for learning.

The Optical Electronics Workshop and other practical electronic workshops:

1. Provide basic instruction in introductory and advanced electronics concepts,
2. Provide low cost electronics resources,
3. Give teachers confidence in ordering and handling electronics components,
4. Provide realistic student projects for the classroom
5. Provide an opportunity for networking, and
6. Learn about high technology, development around the world

The focus of the Practical Electronics Workshops is to help with the proposed new senior physics curriculum, which is in extended trial in Queensland. In addition workshops are intended for middle school science and also design and technology teachers. Griffith University hopes to see this reflected in increased motivation by teachers to introduce their students to practical electronics, which will promote and broaden understanding and interest of possible careers in science and technology.

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