VISIBLE LIGHT DATA COMMUNICATIONS

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ABSTRACT

In the first part of this paper, a general overview of Visible Light Communications (VLC) is described. After an introduction which covers a short historical overview, the main characteristics of this technology including applications and comparisons with other wireless technologies (radiofrequency and infrared communication) are presented. Next, the basic configuration of a VLC system will be covered, including the VLC transmitter, the VLC channel, the VLC receiver and the main modulation techniques used. This part concludes with some challenges being worked, standardization efforts and general conclusions.

In the second part, the practical work of the project is presented. We focused on the electrical and optical characteristics of the VLC transmitter: Light Emitting Diodes (LEDs). Experiments carried out in different commercial LEDs such as I-V characteristics, spectra measurements, Light Power vs. Current characteristics, pulse response and frequency response are described and discussed.

CONTENTS

PART I. VISIBLE LIGHT DATA COMMUNICATIONS.

1. Introduction.

Nowadays, wireless communications has become fundamental to our lives and we transmit a lot of data every day. The main way we transmit wireless data is by using electromagnetic waves, in particular radio waves. However, radio waves can support only limited bandwidth because of restricted spectrum availability and interference. Furthermore, radio spectrum is full to bursting and it is difficult to find radio capacity to support media applications.

There is an emerging wireless communication with a promising future and which can be a complement of radio waves: Visible Light Communication (VLC). VLC is a data communication technology that uses a visible light source as a signal transmitter, the air as a transmission medium or channel and a signal receiving device. Generally, the transmitters are Light Emitting Diodes (LEDs) while the principal device of the receiver is a photodetector, usually a photodiode. By using VLC in short distance applications, we can supplement radio waves achieving high data rates and a larger bandwidth.

Light is part of the electromagnetic spectrum, specifically the visible light spectrum, which covers wavelengths between 380-780nm. We have already a lot of LED-based lights installed in the world and we can use them for communications. A LED is a semiconductor device that has the advantages of fast switching, power efficiency and emits visible light that is safe for the human because it is not harmful to vision. Therefore, we can both illuminate and transmit data everywhere.

1.1 Brief history of Visible Light Communication.

Human being has used a visible light source as a form of data transmission since ancient times. Light sources used and their respective main systems of communication invented by human are listed below [1,2]:

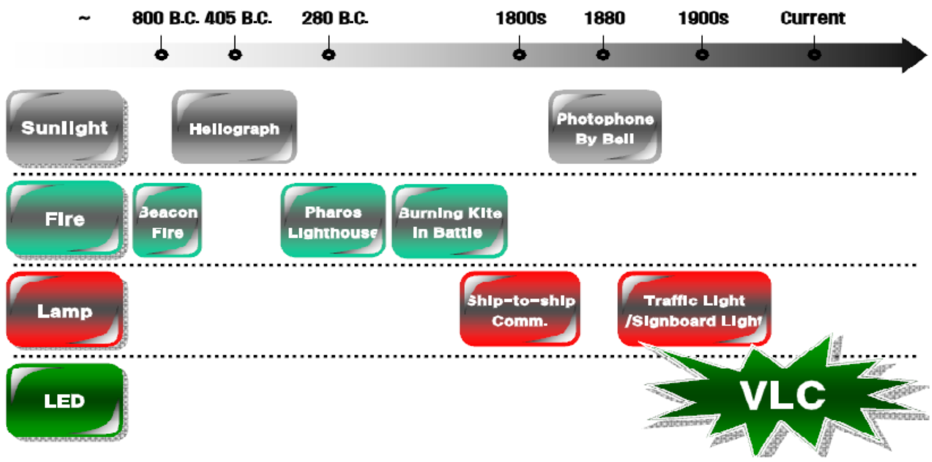
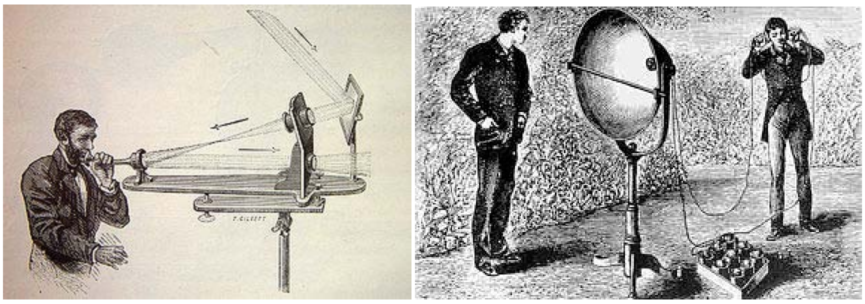


Fig. 1: Historical perspective of Visible Light Communications.

- Sunlight.

-The heliograph was used to send information over large distances by using reflecting mirrors.

-In 1880, Alexander Graham Bell invented the “Photophone”, which allowed transmitting sounds over long distances on a beam of light. It is considered as the first sophisticated wireless communications device.



(a) (b)
Fig. 2: (a) Photophone transmitter. (b) Photophone receiver and handset.

- Fire.

-Beacons were fires lit located on hills or high places, used either as lighthouses for navigation at sea, or for signaling over land that enemy troops were approaching, in order to alert defenses.

-Lighthouses in ancient times were used to help ships navigate by fires built on hilltops.

-Burning kites were used in the battlefield for communication.

- Lamps.

-In ship to ship communication lamps were used for communication (using Morse code).

-Traffic lights are used to control the flow of vehicles or pedestrian crosses using three colors (red, amber and green) to communicate three different messages.

- LEDs.

More recently, since 2003, there have been various researches in VLC for data transmission using LEDs. The most important were made by the Nakagawa Laboratory, Smart Lighting Engineering Centre, Omega Project, D-Light Project, UC-Light Centre and work at Oxford University.

These days, many lighting devices can incorporate a VLC system - we will go into detail later explaining some VLC applications.

2. VLC Characteristics.

As mentioned above, visible light communication is a data communication technology that uses visible light between 380 nm and 780 nm. These wavelengths correspond to a frequency range of approximately 384 THz to 789 THz. In Fig.3, we can see a diagram of the visible light spectrum [3].

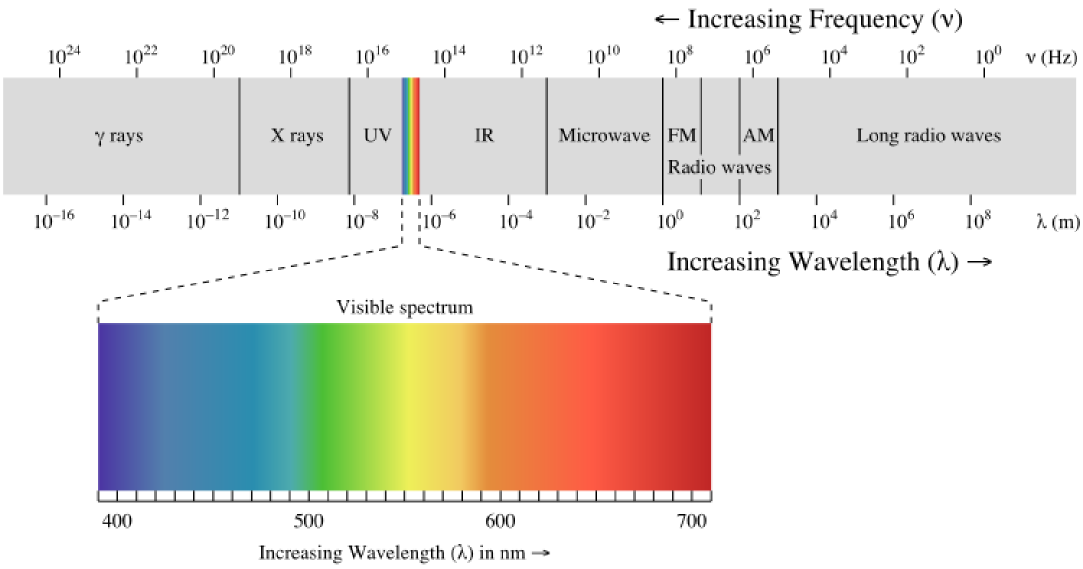


Fig.3: The visible spectrum.

The main characteristics of this technology [4, 5] are summarized below:

- Bandwidth: The bandwidth is virtually not limited; it offers a frequency band of approximately 400THz.
- Efficiency: We can both transmit data and illuminate so it is a high efficiency technology.
- Data rates: VLC can achieve high data rates (hundreds of Mb/s) and it can therefore be used for high speed wireless communications.
- Cost: As VLC uses the visible light spectrum it is free of cost. Furthermore, transmitters and receivers are cheap.
- Human safety: VLC is harmless to human health and it is not injurious to the human eye.
- Omnipresent nature. We have the infrastructure because there are already a lot of LED-based lights installed in the world which are potential VLC transmitters and therefore we can use them for communications.
- Security: As light waves do not penetrate opaque objects they can not be intercepted, so it offers a very secure communication. It is very difficult for an intruder to make use of your signal.

- Visibility: It is great to see data being communicated by a beam of light. What you see is what you send!

2.1 VLC versus Radio Waves.

Although radiofrequency communications is the most popular technology today, it has also disadvantages. Therefore, we can compare VLC with radiofrequency using five main concepts:

- Capacity.

Radio spectrum is full and it is difficult to find radio capacity to support the demand of wireless data transmissions for media applications: radio waves are limited, expensive and we only have a certain range of it. By using VLC we have more spectrum and we have the infrastructure because there are lots LED-based lights installed in the world that are potentially VLC transmitters. We can then compare the available bandwidth:

$$\Delta f\ (RF) \sim 300\ GHz$$

$$\Delta f\ (VLC) \sim 400\ THz$$

- Efficiency.

Radio waves consume a lot of energy while VLC is highly energy efficient because we can illuminate and transmit data at the same time. Furthermore, VLC transmitters and receivers devices are cheap and there is no need for expensive RF units.

- Availability.

Radio waves cannot be used in some sensitive scenarios like hospitals, aircrafts… due to interferences with other devices. On the other hand, we can use VLC when there is light and no interference with radiofrequency based systems exits. Hence, we can use this technology in many places.

- Security.

Radio waves penetrate through walls and they can be intercepted. If someone has bad intentions, he can make use of your network. By using VLC we only transmit data where the light is because light does not penetrate through walls, that is to say, we have a very secure data communication.

- Human health.

The transmission power of radio waves van cannot be increased over a certain level because there are serious health risks for humans. As VLC is harmless for the human body we can increase the transmission power if needed.

2.2 VLC versus Infrared Communications.

Another important wireless data-transmission technology widely used in many applications such as mobile phones or laptops is Infrared (IR) Communication. Infrared light is a electromagnetic radiation with a wavelength longer than that of visible light, measured from the nominal edge of visible red light at 0.74 µm, and extending conventionally to 300 µm. These wavelengths correspond to a frequency range of approximately 1 to 400 THz, so both the IR and visible light communications have a similar bandwidth.

However, in IR communications, data rates cannot be increased over a certain level as it has serious threat to the human eye, so this problem can be solved by using VLC because it is suitable to the human eye in terms of visibility. Moreover, we can obtain higher data rates with VLC.

2.3 VLC Disadvantages.

Although it seems to be a “perfect” technology, VLC has also drawbacks. The main disadvantages of VLC are listed below:

-A VLC system is prone to interference from other light sources, like the sunshine, incandescent light, fluorescent lamp, etc.

-The range of VLC is quite short; it works over a few meters.

-Another important disadvantage is that VLC requires a line of sight (LOS), in other words, we can only transmit data where the light is.

2.4 VLC Potential Applications.

There are several future applications for visible light communications; the most important and interesting are listed below[6,7]:

- Aviation.

Radio waves can not be used by passengers in aircrafts. LED-based lights are already used in aircraft cabins and each of these lights could be potentials VLC transmitters to provide both illumination and media services for passengers. Furthermore, this will reduce the aircraft construction costs and its weight.

Fig.4: VLC in an aircraft cabin.

- Smart Lighting.

Smart buildings require aesthetic lighting. Smart lighting with VLC provides the infrastructure both for lighting and communication and will reduce the circuitry and the energy consumption within an edifice.

- Hazardous Environments.

In environments such as petro-chemical plants, mines, etc RF is potentially dangerous because there are explosion risks, so communication becomes difficult. VLC can be interesting in this area as it is a safe technology and provides illumination and communication at the same time.

- Device Connectivity.

By pointing a visible light at another device you can have a very high speed data link and with security because you can shine a beam of light in a controlled way.

- Vehicle and Transportation.

Traffic lights and many cars use LED-based lights. Cars can communicate to each other to prevent accidents and also traffic lights can communicate to the car to ensure road safety.

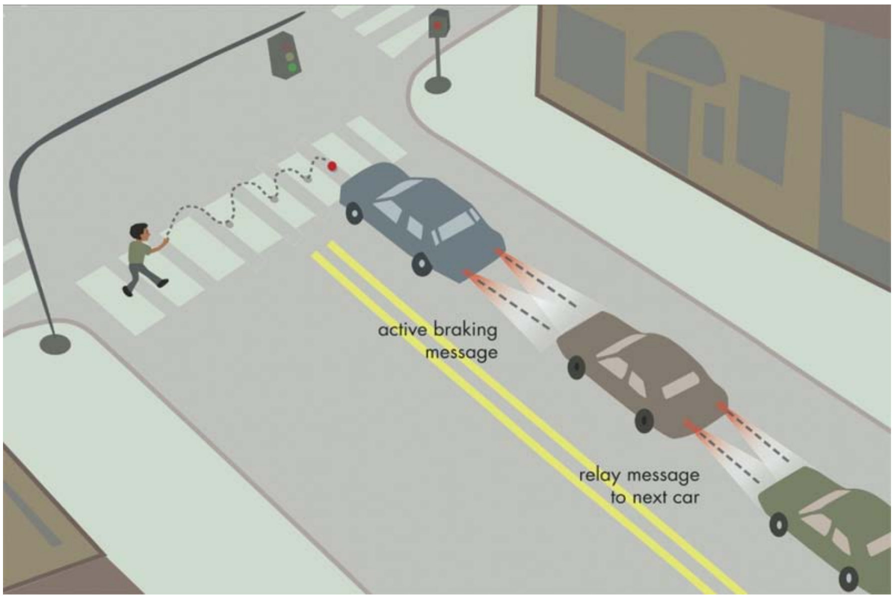


Fig. 5: By using VLC, vehicles can communicate to each other and prevent accidents.

- Defense and Security.

VLC can enable secure and high data rate wireless communications within military vehicles and aircraft.

➢ Hospitals.

In hospitals, there is some equipment that is prone to interference with radio waves, so using VLC has many advantages in this area.

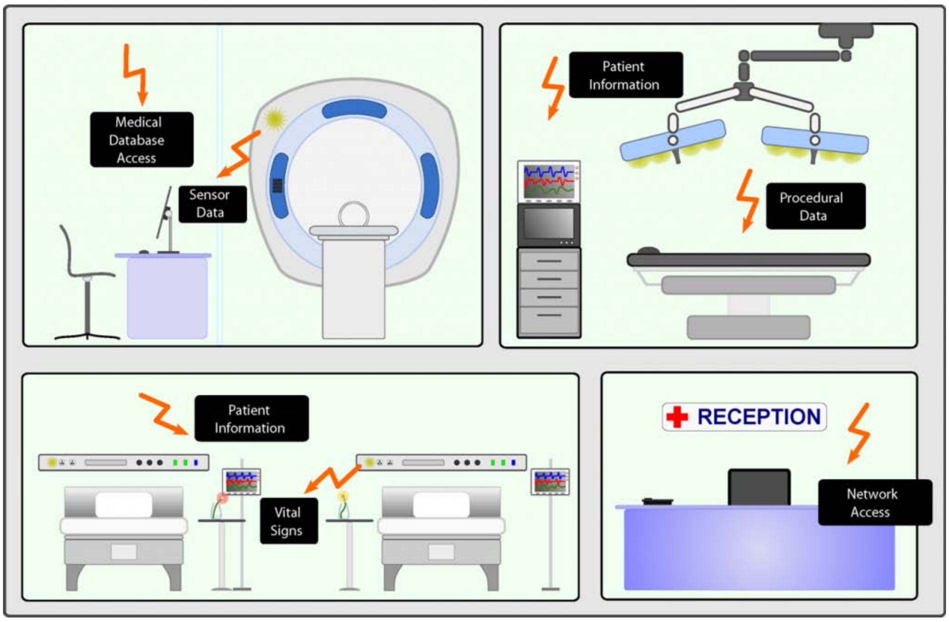


Fig. 6: Medical equipment sensitive to radio wakes can work with VLC.

➢ Underwater Communications.

VLC can support high data rates beneath the water, where other wireless technologies like RF do not work. Thus, communications between divers or remote operated vehicles are possible.

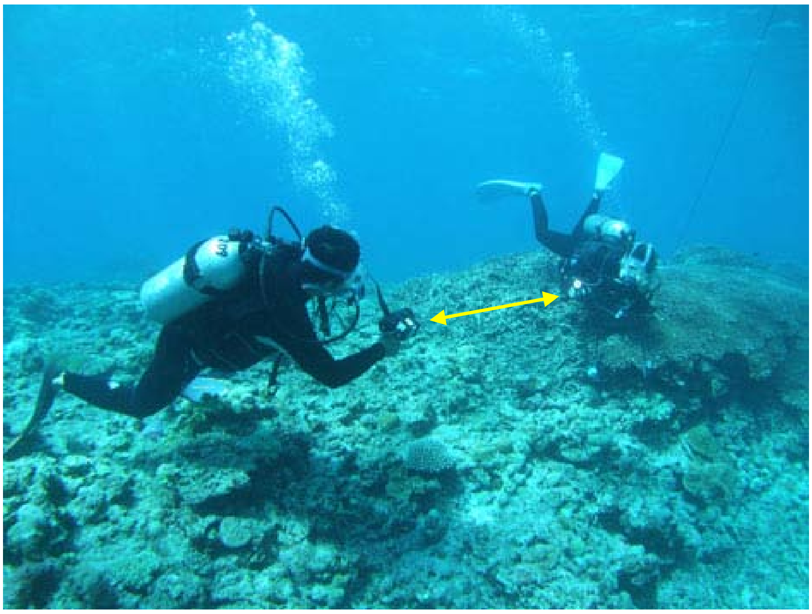


Fig. 7: VLC in underwater communications.

3. VLC System Architecture.

In this chapter, we introduce the basic configuration of a VLC system: the VLC transmitter, the VLC channel and the VLC receiver.

3.1 VLC Transmitter.

The components of the VLC transmitter are visible solid-state emitter; this can be either an LED or a semiconductor laser, depending on the application. Both lasers and LEDs have been used for data communications, but when the VLC transmitter must act as a communication transmitter and an illumination device at the same time white light LEDs are used. In the following section we will consider white LEDs for illumination and data communications. (General information about LEDs can be found in [8]).

3.1.1 White light LEDs.

There are two main ways to produce white light: white light sources based on LEDs and white light sources based on wavelength converters.

3.1.1.1 White light sources based on LEDs.

The generation of white light with LEDs can be achieved with a huge number of possible spectra and can be based on dichromatic, trichromatic or tetrachromatic sources, as shown in Fig. 8. [9]

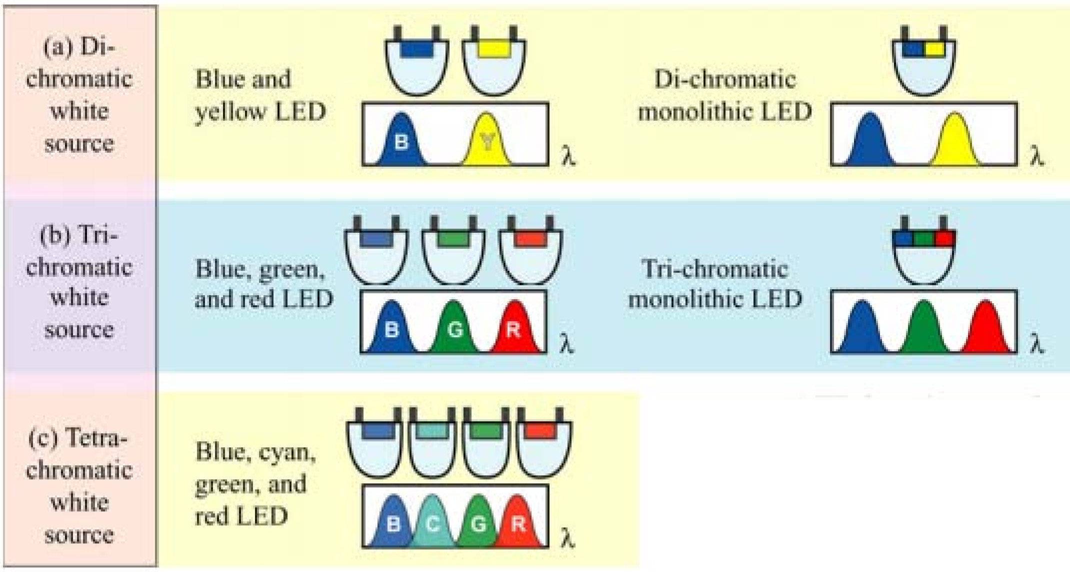


Fig. 8: White- light sources based on LEDs. [4]

However, the most common used are trichromatic sources (red, green and blue) on a single chip, also called RGB LEDs. All the three colours are emitted simultaneously. This three colour mixer has many advantages such as a wide bandwidth and therefore higher data rates.

3.1.1.2 White light sources based on wavelength converters.

Most white light emitters use an LED emitting a short wavelength and a wavelength converter. There are many types of converter materials such as phosphors, semiconductors and dyes, but the most common wavelength converter materials are phosphors. Again, the generation of white light with wavelength converters is based on dichromatic, thrichromatic and tetrachromatic sources. (See Fig.9 below) [9]

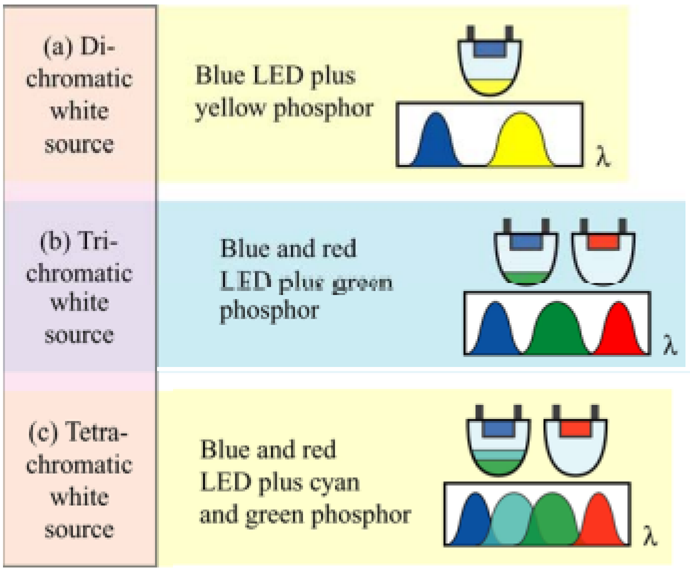


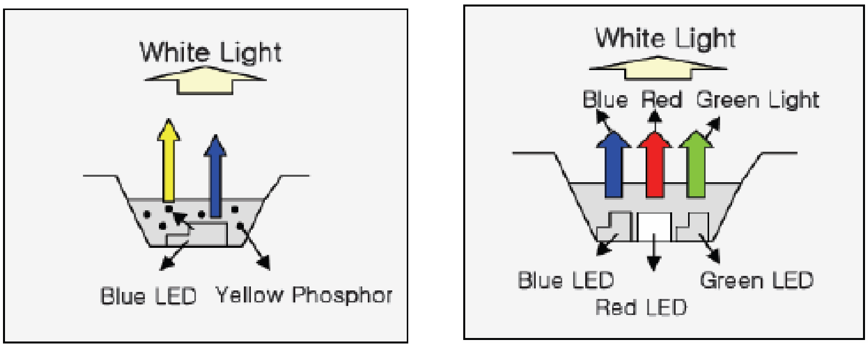
Fig. 9: White-light sources based on wavelength converters.

The most applied type of white light source is the white light LED which uses blue light and an exciting phosphor on a single chip.

3.1.1.3 RGB LEDs vs. Phosphor-based LEDs.

RGB LEDs have a bigger bandwidth and therefore can achieve higher data rates. However, they require more difficult modulation techniques and are more expensive than Phosphor-based LEDs. The following table shows a comparison between RGB LEDs and Phosphor-based LEDs:

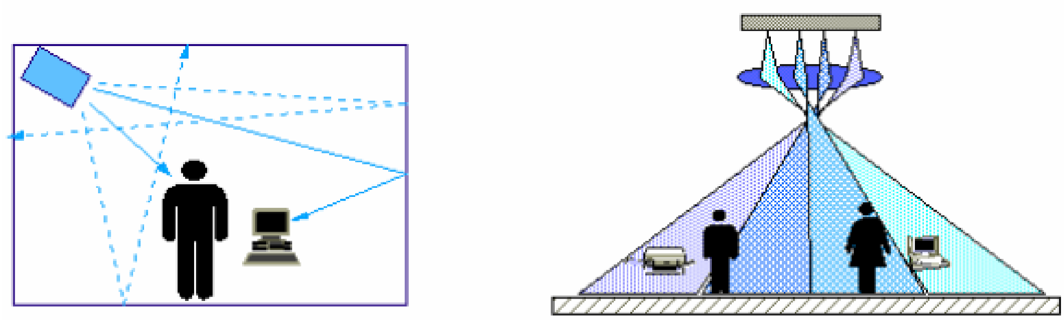
	RGB LEDs	Phosphor-based LEDs
Data rates	≅100 Mbps	≅40 Mbps
Price	More expensive	Low cost
Bandwidth	Higher bandwidth	Phosphor limits the bandwidth
Modulation	Complex	Low complex



(a) (b)
Fig. 10: (a) Phosphor-based LED. (b) RGB LED

3.2 VLC Channel

The VLC optical channel consist of a line of sight (LOS) or a number of LOS components that correspond to the paths from lighting sources to the receiver and a diffuse component created by reflections of walls or objects in the room. The LOS component is modeled in [10] and the approaches described in [11-13] can be used for the diffuse component.



(a) (b)
Fig. 11: (a) Diffuse channels. (b) Line of sight channel.

3.2.1 Interferences with other light sources.

Ambient light interference affects the VLC channel. Ambient light noise can be caused by other light sources such as incandescent lights, fluorescent lamps or the sunlight. Incandescent lights emit high levels of infrared radiation, fluorescent lamps emit higher levels in the visible spectrum range and the sunlight emit both high levels of ultraviolet radiation and a considerable amount of infrared radiation.

Sunlight causes extra photocurrent which depends on the wavelength detected and on the environment. This photocurrent can be blocked by an AC coupling of the receiver. However, the white noise of the shot noise that this light contributes is not blocked and at high light levels the photodetector can lead to saturation. One possible solution to avoid this noise source would be the use of an optical interference filter. This filter (placed on the photodiode) would allow the receiver to detect signals of a certain wavelength. On the other hand, the use of such a filter would reduce the strength of the detected signal making the device less sensitive and therefore more susceptible to receiving errors. [1, 14-15]

Incandescent lights and fluorescent lamps create electrical interference photocurrent harmonics. This problem could be reduced with electrical filtering. [1, 15]

There have been few published researches about the effects of other light sources interferences on the VLC channel and more investigation is required on this area.

3.3 VLC receiver.

The VLC receiver is composed of an optical concentrator, optical filter, photodetector and amplification circuit. Fig.12 shows a schematic diagram of a typical receiver. [15, 16]

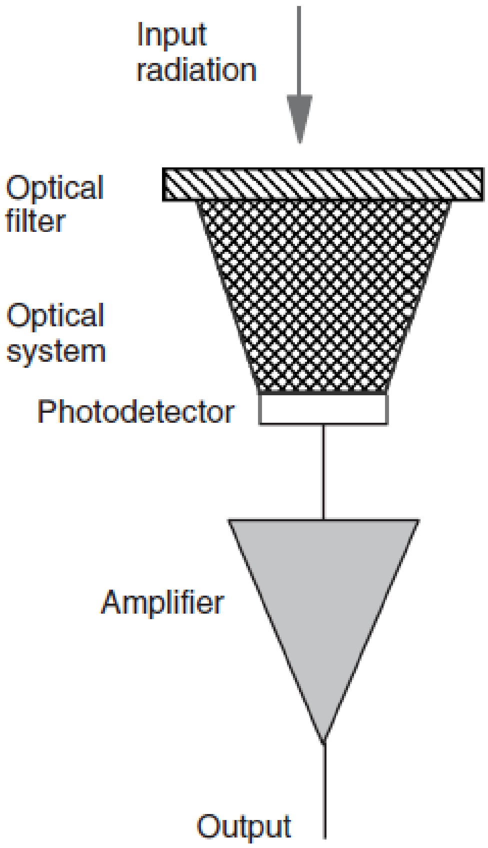


Fig. 12: Block diagram of the optical receiver.

The main element is the photodiode that is a type of photodetector able to convert light into a photocurrent. For VLC, Silicon Photodiodes are used; they operate in a wavelength range of 190-1100 nm, so they show a good responsivity at the visible light wavelength region (380-780 nm). Both PIN photodiodes and avalanche photodiodes (APD) can be used, but for usual applications PIN photodiodes are sufficient. The PIN photodiode has not a high gain like the APD, but it is cheaper, presents a larger active area and it is more convenient in high noise scenarios.(Further information about photodetectors, see [17]).

To detect the maximum signal (power) a big active area is required, but increasing the area of the detector often decreases the bandwidth. When the VLC bandwidth requirements are relatively low a large detector area can be utilized.

The optical concentrator is used to compensate for high spatial attenuation due to the beam divergence from the LEDs to illuminate large area. The VLC system is vulnerable to the sunlight and other illuminations, so it is important to implement a suitable optical filter to receive signals of a certain wavelength band and reject unwanted noise components. Regarding to the amplifier, there are several types of amplification circuits that we will not go into detail.

3.4 Modulation for VLC.

In order to send out data via LEDs it is necessary to modulate the information into a carrier signal. The IEE 802.15.7 standard [18] for VLC covers both the physical layer (PHY) and the medium access control (MAC), but we will focus on the physical layer. The physical layer is divided into three types (PHY I. PHY II and PHY III) and each PHY contains different modulation schemes. In this chapter, a brief description of the data modulation schemes and the physical layer will be presented.

3.4.1 Modulation schemes.

The main modulation methods for VLC are introduced in the following. Note that for all the modulation schemes listed below there are many variants that we will not go into detail.

- On-Off Keying (OOK). OOK modulation is the simplest modulation scheme for VLC, as the LEDs are turned on or off depending if the data bits are "1" or "0". In the easiest form, a digital 1 represents the light ON state and a digital 0 represents the light OFF state. The 802.15.7 standard uses Manchester encoding which embeds the clock into the data by representing a logic zero as an OOK symbol "01" and a logic one as an OOK symbol "10". In this manner, the period of the positive pulses is the same as the negative ones but also doubles the bandwidth required for OOK transmission. For higher data rates run length limited (RLL) coding is used because is more efficient.

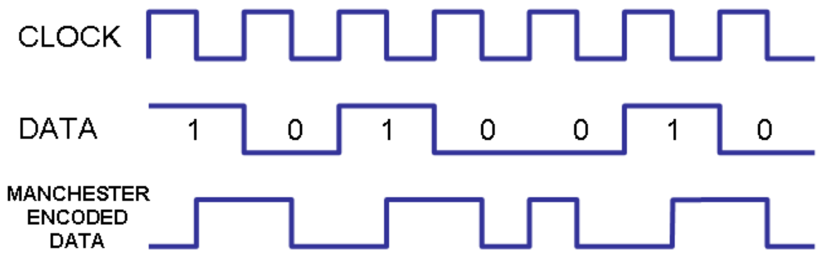


Fig. 13: Manchester coding for OOK.

- Variable Pulse Position Modulation (VPPM). VPPM changes the duty cycle of each optical symbol which is distinguished from others by the pulse position to encode bits. The variable term in VPPM represents the change of the pulse width (duty cycle) in response to the requested dimming level. The logic 0 and logic 1 are symbols are pulse width modulated depending on the dimming duty cycle requirement.

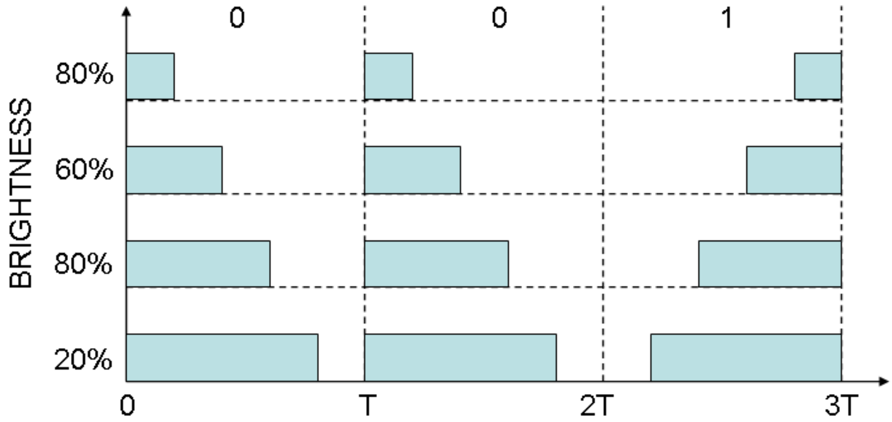


Fig.14: Variable Pulse Position Modulation.

- Colour Shift Keying (CSK). This system can only be used if the light source of the VLC system uses RGB LEDs and the bit patterns are encoded to colours. CSK has the following advantages:

  -The final output colour, e.g white, is guaranteed by the colour coordinates.
  -The output data can be carried by the colour itself so the total output power is near constant.
  -It provides higher data rates at a lower clock frequency.

  The x-y chromaticity diagram in Fig. 15 shows the colour space and the associated wavelengths in the outer curve (in nm). Mixing of the red, green & blue primary sources produces the different colours which are coded as information bits.

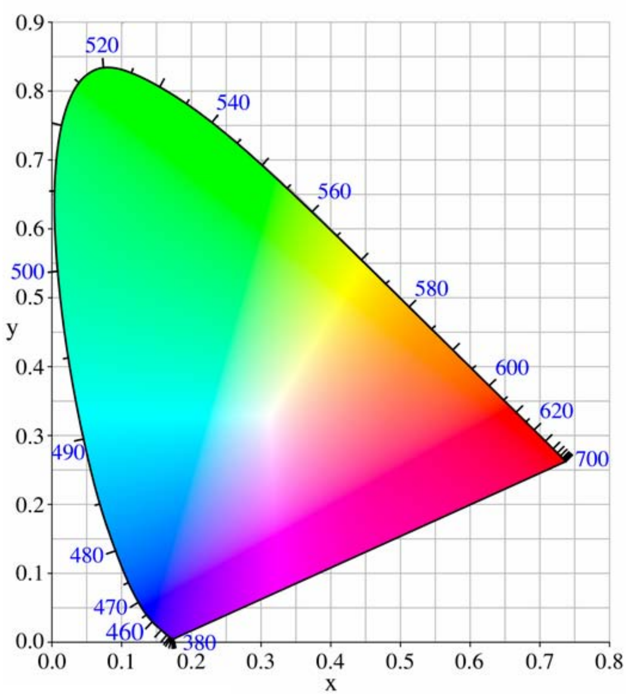


Fig.15: Chromacity diagram for CSK.

3.4.2 The physical layers.

- PHY I. It is defined for a single light source in outdoors low data rate applications. It operates from 11.67 to 266 Kb/s and supports OOK and VPPM.

- PHY II. It is defined for a single light source and it is designed for indoor applications with data rates between 1.25 and 96 Mb/s. It supports both OOK and VPPM.

- PHY III. It uses multiple optical sources with different frequencies (colours) and operates from 12 to 96 Mb/s. The modulation method is CSK.

4. Challenges.

The major challenge for VLC is to increase the modulation bandwidth of the LED, including RGB and phosphor-based LEDs. When using a phosphor-based LED, the most common method is to use an optical filter to detect only the blue component at the receiver and block the slow time constant of the phosphor. Although this increases the bandwidth, the channel bandwidth is still low.

In [19], the effect of the slow phosphor is demonstrated. The modulation bandwidth of a Luxeon Star device is measured and results show a bandwidth of about 3 MHz for the white emission and 12 MHz for the blue emission (see Fig.16 below).

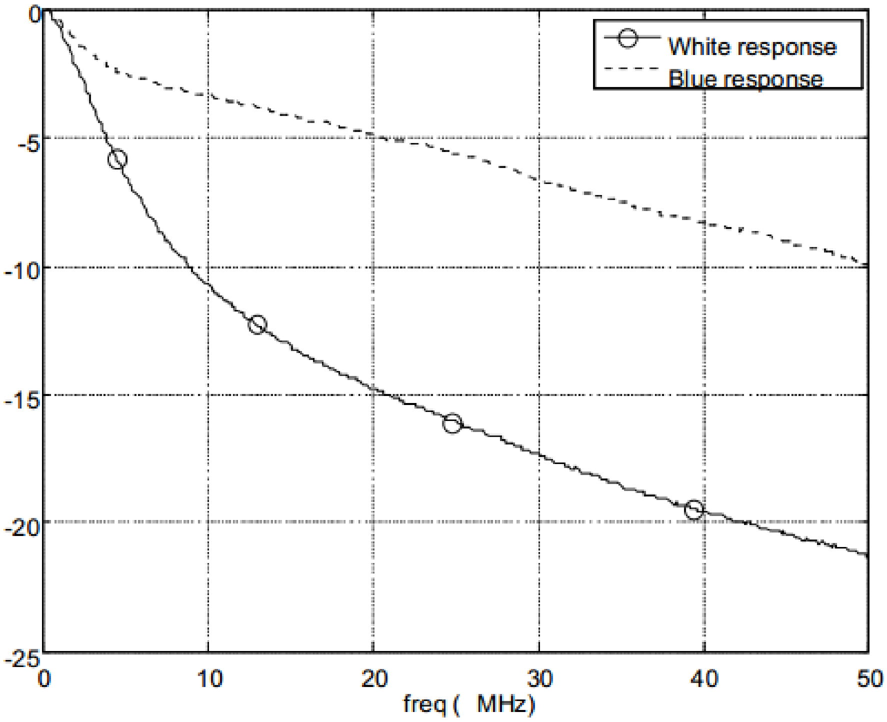


Fig.16: Measured bandwidths in [19] of Luxeon Star device, showing white and blue responses.

4.1 Equalisation.

The channel response can be equalised at the transmitter (pre-equalisation), at the receiver (post-equalisation) or a combination of both. At the moment it is not known which technique will provide highest data rates. Many investigations have been carried out in this area:

a) Pre-equalisation.

Equalisation at the transmitter has been investigated and this can increase the data rate and the bandwidth; this technique allow to compensate the quickly fall-off in response of white LEDs at high frequencies.

Most LED lighting applications consist of an array of LEDs, and it is possible to equalise each device separately so the overall response of the array provides higher bandwidth than individual devices. A prototype has been built using this technique [20]. Results show that using an array of 16 LEDs, each with a bandwidth of 3 MHz, the overall response of the system was 25 MHz and a data rate of 40 Mb/s using Non-Return to Zero (NRZ) On-Off Keying (OOK).

Equalisation of a single chip combined with blue filtering has also been undertaken in [21], where a data rate of 80 Mb/s was achieved using NRZ-OOK.

b) Post equalisation

Equalisation at the receiver has been tested in [22] and this can improve data rates using a simple first order equaliser to compensate the narrow bandwidth of the phosphor-based LED.

4.2 Parallel data communication.

In lighting applications many LEDs are used to provide the required illumination. Sending different data from each LED to a receiver array with each photodetector illuminated by one device (different information from each stream) is a good option to increase the overall data rate of the system. This technique is called Optical Multi-Input Multi-Output (MIMO).

4.3 Providing an uplink.

Although VLC in a natural broadcast medium, sometimes it is required to send information back to the transmitter and providing an uplink is challenging. Several approaches have been considered:

1) A retroreflector can be used to return incident light back to the source. The light is modulated upon reflection with the data that is to be sent back to the transmitter. In [23] low data rates were achieved and this technique requires further studies.

2) The use of RF [24] has also been considered. The VLC downlink can be combined with a RF uplink. Although relative high data rates can be achieved there is no VLC used for the uplink which could be undesirable in sensitive scenarios.

3) Also, the VLC light source can be co-located with a VLC receiver, but this will increase the price of the system, it is less energy efficient and it might look unsightly to some smart applications.

5. Standarisation activities.

In Japan, the Visible Light Communication Consortium (VLCC) [4] have published two JEITA (Japan Electronics and Information Technology Industries Association) standards, JEITA CP-1221[25] and JEITA CP-1222[26].

In the Institute of Electrical and Electronics Engineers (IEEE), The IEEE 802.15.7 [18] Visible Light Communication Task Group has completed a PHY and MAC standard for Visible Light Communications (VLC).

In the Wireless World Research Forum (WWRF), the working group 5 has published a white paper on VLC.

6. Conclusions.

In this part, the main ideas on Visible Light Communications (VLC) have been presented. Although most existing efforts are still in development, VLC is a wireless technology with a promising future and with a wide prospective of applications where other wireless technologies (i.e. Radiofrequency) cannot be implemented, like underwater communications, aircrafts, hospitals, etc. Also, it can be considered as a good to complement to them; the radio spectrum is full to bursting and it is difficult to find capacity for media applications, so the capacity can be loaded off to the visible spectrum.

As LEDs are considered the next generation of lighting devices, VLC using LEDs both for illumination and communications can be a viable option in outdoor and indoor environments. By using VLC we can achieve high data rates in short distances and a secure communication as data is sent where the light is and light waves are difficult to intercept.

Probably, the main limitations of a VLC system are the modulation bandwidth of the LEDs and that it presents interferences with other light sources, so further work need to be carried out in these areas. Other challenges for VLC are increasing the transmission rate improving both the LED and receiver bandwidth through equalisation, the provision of an uplink and improving the standardization in order to commercialize VLC systems in a near future.

PART II. EXPERIMENTAL WORK.

In this section, experiments carried out that are very useful to investigate both the electrical characteristics and the optical properties of LEDs are described: I-V Characteristics, Spectra Measurements, Light Power versus Current Characteristics, Pulse Response, Frequency Response and calculations of the LEDs efficiency. We tested 8 different commercial LEDs of different colours and diameters: Red, Green, Blue and White of 3 mm and 5 mm each. Datasheets of the LEDs can be found in the Appendix A section.

1. I-V Characteristics.

1.1 Introduction.

[9, 17, 27] The operation of an LED is commonly described by a special graph called I-V characteristic curve. This curve shows the relationship between the voltage applied from anode to cathode and the resulting current that flows through the device.

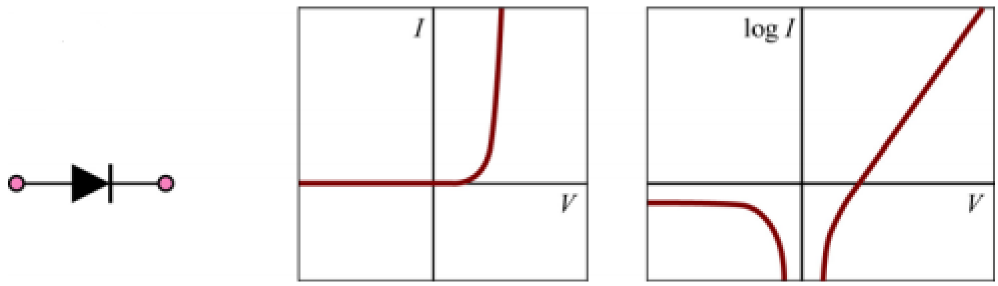


Fig.1: Ideal I-V characteristic of a diode.

The ideal I-V characteristic of a p-n junction is given by the Shockley equation:

$$I = I_S \left[e^{\frac{qV}{K_B T}} - 1 \right]$$

Where "I_S" is called the saturation current, which depends on the size of the device, material, doping, temperature and other parameters of the material.
"q" is the elementary charge.
"K_B"is Boltzmann constant.
"T" is the temperature, in Kelvin.

In forward bias conditions, when the diode voltage is larger than the thermal voltage V>>$\frac{K_B T}{q}$, the "-1" can be dropped and we can rewrite the Shockley equation as

$$I \cong I_S \left[e^{\frac{qV}{K_B T}} \right]$$

The Shockley equation gives the expected theoretical I-V characteristic of a p-n junction, but to describe experimentally measured characteristics the following formula is used:

$$I \cong I_s \left[e^{\frac{qV}{nK_BT}} \right]$$

Where "n" is the ideality factor of the diode that measures how close the diode is to this equation. Thus, an ideal diode has n=1, and the closer the ideality factor is to 1 the closer the diode is to the ideal case. For real diodes values higher than n=2 have been found.

The most important parameter in the I-V curve of a LED is the turn on voltage or threshold voltage. The threshold voltage for a LED is the point from which the current increases sharply with the voltage. The turn on voltages are slightly different for each LED colour, but usually of order 1 to 4 Volts. Normally, red LEDs have the lowest turn on voltages and as the color moves up in the colour spectrum toward blue, the turn on voltage increases. A typical I-V curve for an LED is shown below:

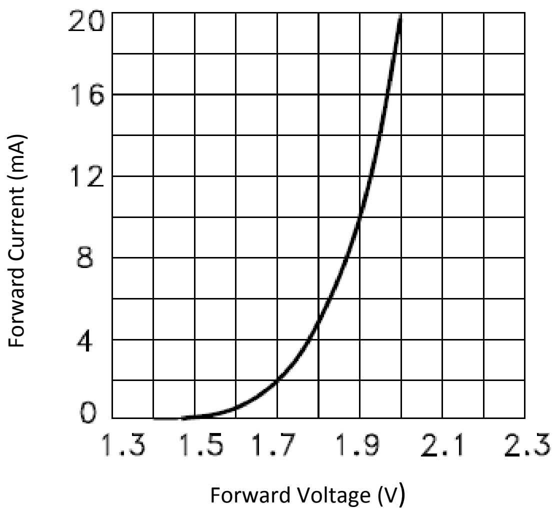


Fig.2: Typical I-V characteristic of an LED.

In the curve above, notice that the LED draws no current under 1.5 volts and therefore the LED is off. Above 1.5 volts the LED draws almost no current with the voltage until at 2 V the current starts increasing steeply and the LED is fully on: the threshold voltage for this LED is 2 Volts.

Moreover, the turn-on voltage for a light emitting device is approximately the bandgap energy divided by the fundamental charge:

$$V = \frac{E_g}{q}$$

Normally a diode has parasitic resistances and a detailed inspection of the diode I-V characteristic as well as logarithmic scale allows for the diagnostic of potential problems such as series resistances, shunts, premature turn on and parasitic diodes. Some deviations from the I-V characteristic are listed below:

- Diode with series resistance: A series resistance can be caused by excessive contact resistance. A diode with a series resistance shows a deviation at high currents.

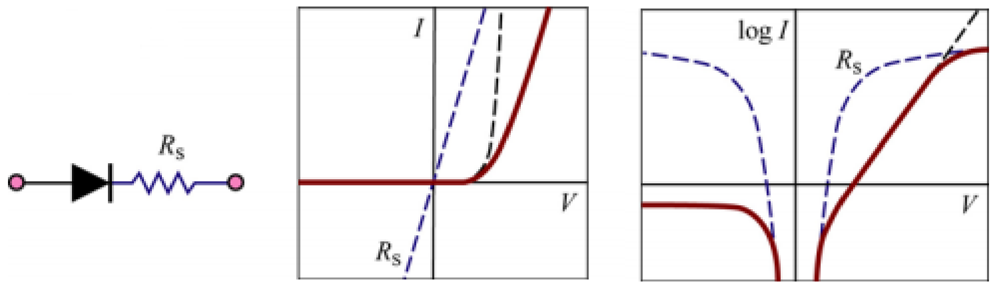


Fig.3: Diode with series resistance I-V characteristic.

- Diode with shunt (parallel resistance): A parallel resistance can be originated by a damaged region of the p-n junction or surface defects. The characteristic by which a shunt can be recognized is shown above. In the logarithmic plot we can appreciate that there is “hump” at forward bias about the same level the reverse saturation current.

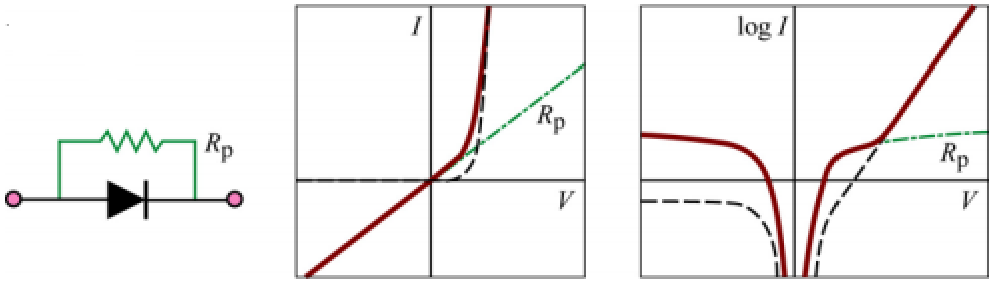


Fig.4: Diode with a parallel resistance I-V characteristic.

- Photocurrent: When carrying out practical measurements with transparent diodes in lighted spaces a photocurrent could be generated. That is why measurements should be done in the dark to reduce the photocurrent.

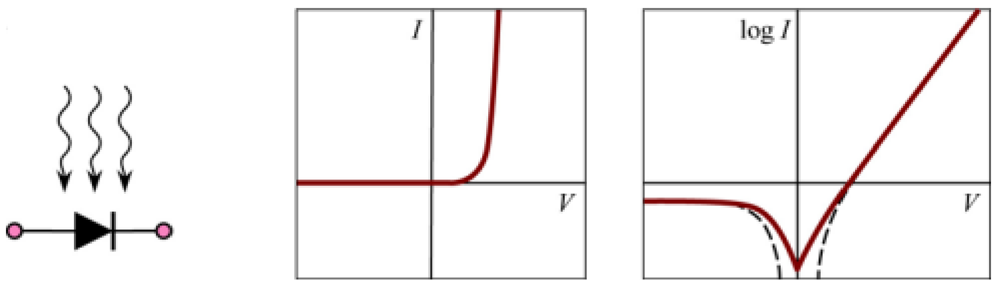


Fig.5: Diode with a photocurrent I-V characteristic.

➢ Diode with shunt and series resistance: The effects of a parallel and series resistance can be seen below.

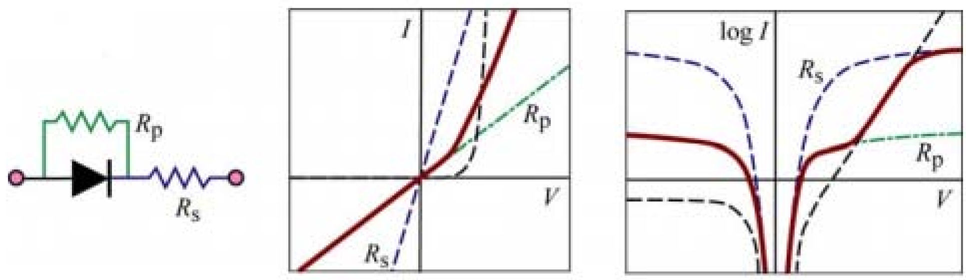


Fig.6: Diode with series and parallel resistances I-V characteristic.

➢ Diode with other parasitic diode that has a lower threshold voltage and a smaller area: Diodes like this present a sub-threshold turn on voltage. In this case, the “hump” in the logarithmic graph has not the same level as the reverse saturation current.

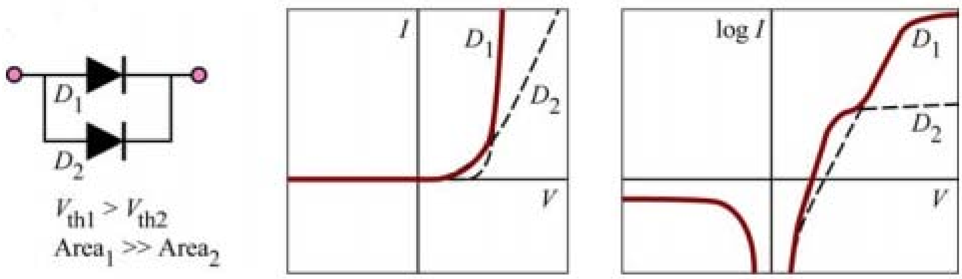


Fig.7: I-V characteristic of a diode with other parasitic diode.

With an R_p and an R_s, the I-V characteristic of the forward biased p-n junction diode is given by

$$I - \frac{(V - IR_s)}{R_p} = I_s \exp\left[\frac{(V - IR_s)q}{n_{ideal} K_B T}\right]$$

1.2 Motivation.

The purposes of these experiments are:

-To investigate the I-V characteristics of different Light Emitting Diodes and measure the threshold voltage for each LED.

-Identify possible deviations from the ideal I-V characteristic.

1.3 Equipment Required.

-LEDs.
-DC power supply.
-Digital multimeter.

1.4 Setup.

The LED is switched on through a high-speed wire with DC power supply, with which we can measure both the voltage and the current applied to the LED and we take several readings Current- Voltage in order to get more accurate results. Also, it is possible to use a digital multimeter to get more precise measurements.

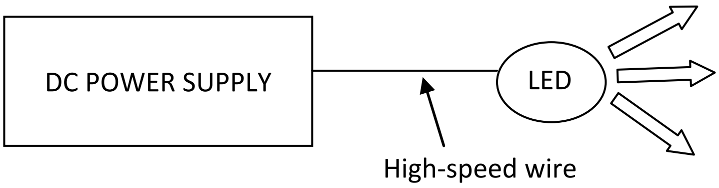


Fig.8: Block diagram of the setup for the I-V characteristics experiment.

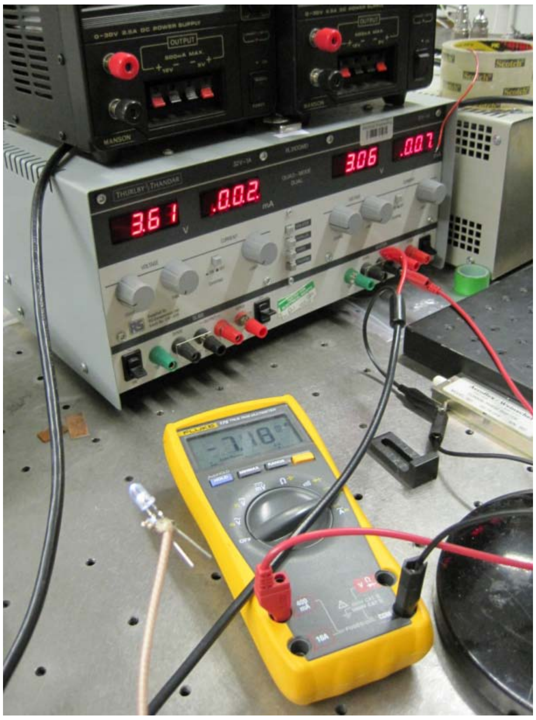


Fig.9: Photography of the setup for the I-V characteristics experiment, taken in the laboratory.

1.5 Results.

Our equipment was not sensitive enough to give an accurate value of the saturation current. The reverse saturation current for the LEDs is very small, less than microamps, so the equipment just gives zero for the reverse saturation current. We only made measurements under forward bias conditions; it is the region where we are more interested to determine the threshold voltage.

1.5.1 Blue LED 3 mm.

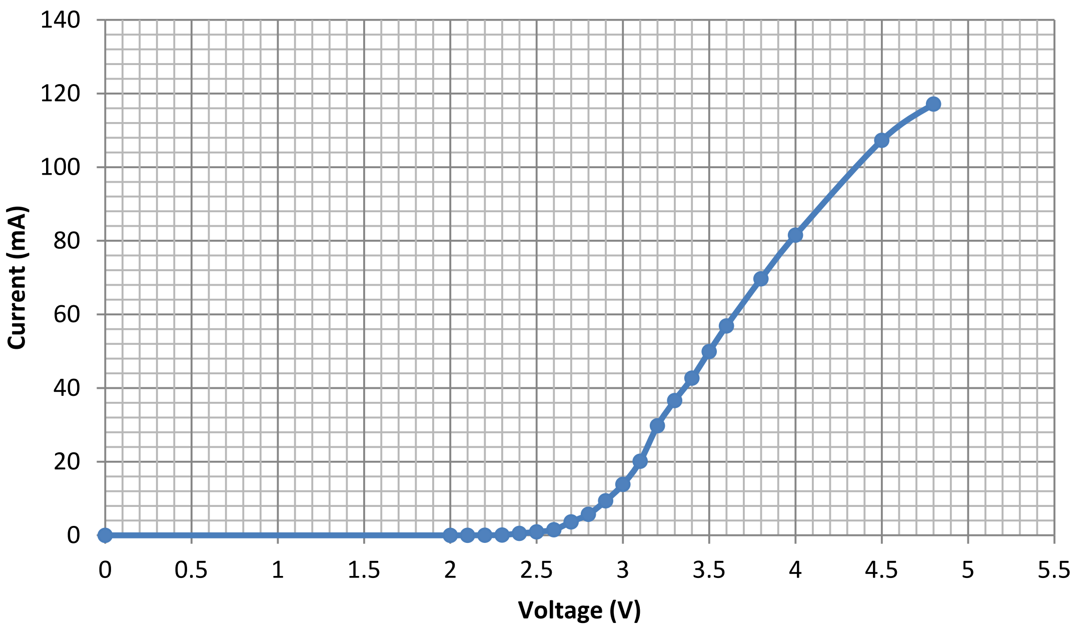


Fig.10: Blue LED 3 mm - I-V Characteristic.

For voltages under 2.6 V the current of the blue LED 3 mm is nearly zero. The point at which the current increases steeply with the voltage (turn on voltage) is 3.2 V.

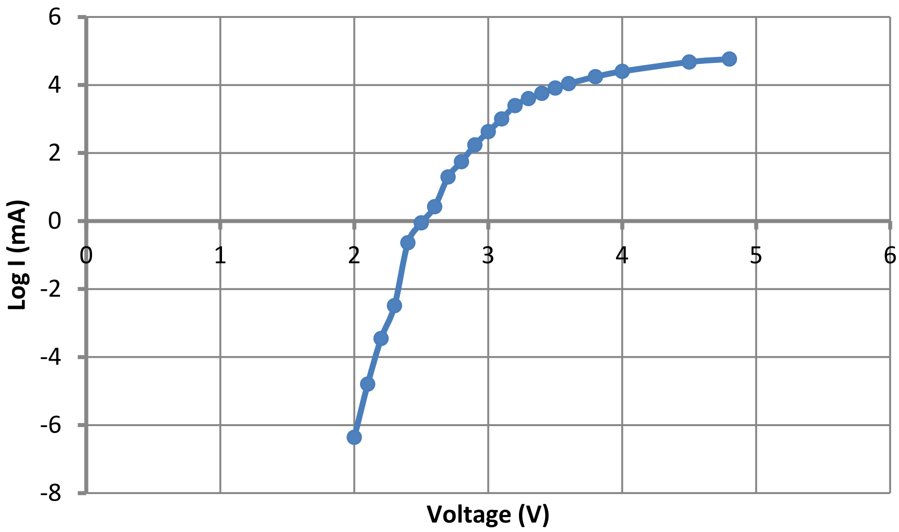


Fig.11: Blue LED 3 mm - Log I vs. Voltage.

By analyzing the I-V curve in a logarithmic scale we can see that the blue LED of 3 mm presents a series resistance.

1.5.2 Blue LED 5 mm.

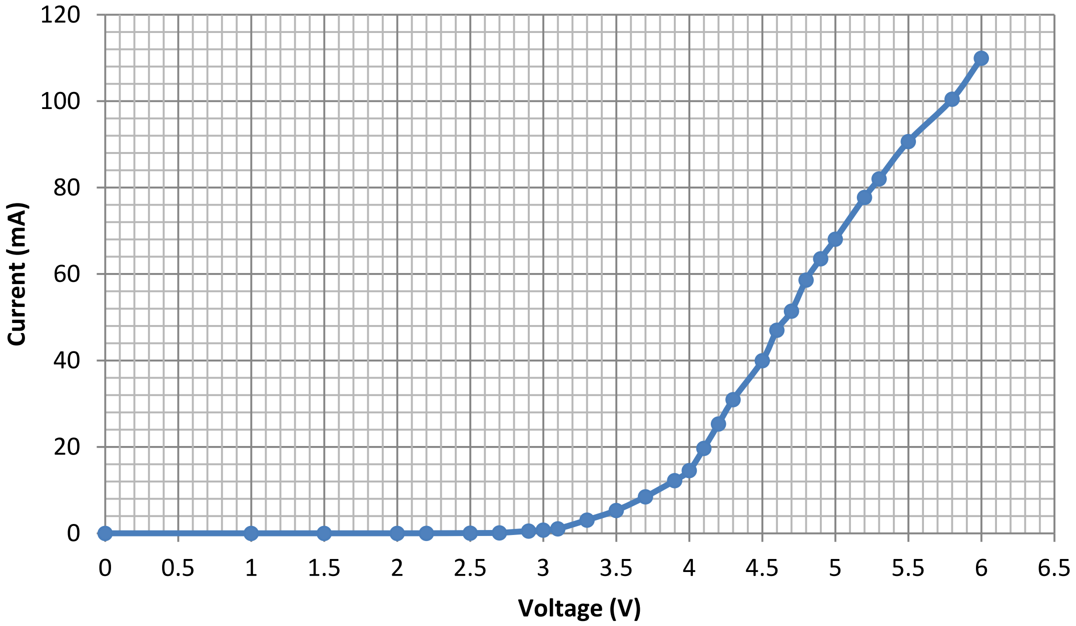


Fig.12: Blue LED 5 mm - I-V Characteristic.

The blue LED 5 mm draws almost no current for voltages below 3.1 V. The turn on voltage for the blue LED 5 mm is approximately 4.1 V.

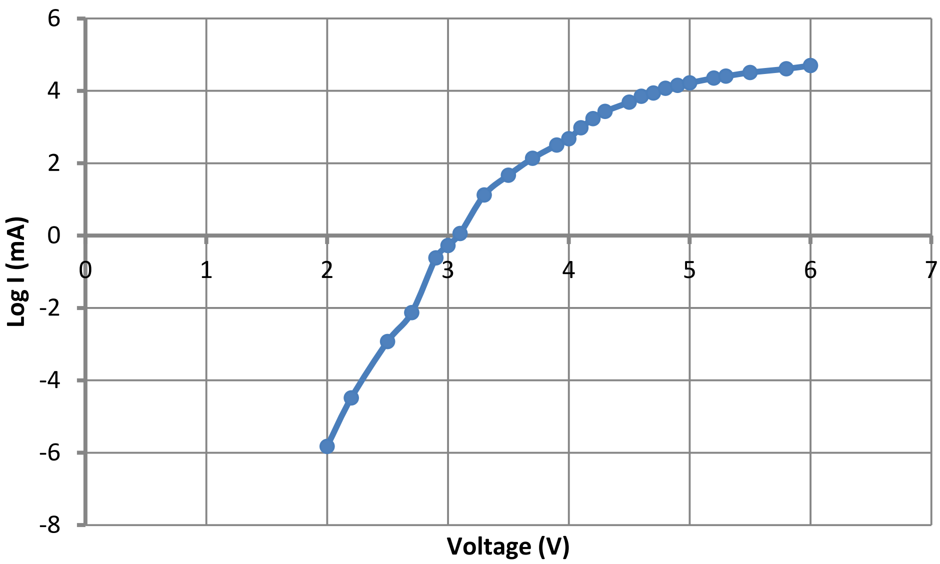


Fig.13: Blue LED 5 mm - Log I vs. Voltage.

The logarithmic plot of the blue LED 5 mm I-V characteristic shows that the device has a series resistance.

1.5.3 Green LED 3 mm.

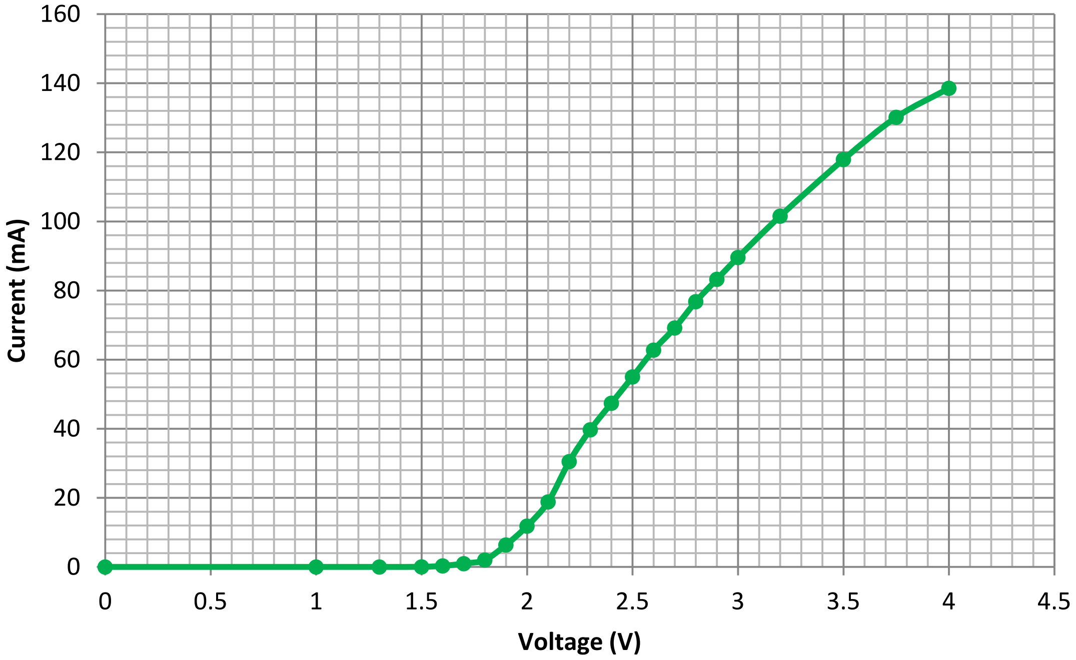


Fig.14: Green LED 3 mm - I-V Characteristic.

For the Green LED 3 mm, the I-V curve shows that the turn on voltage is about 2.1 V.

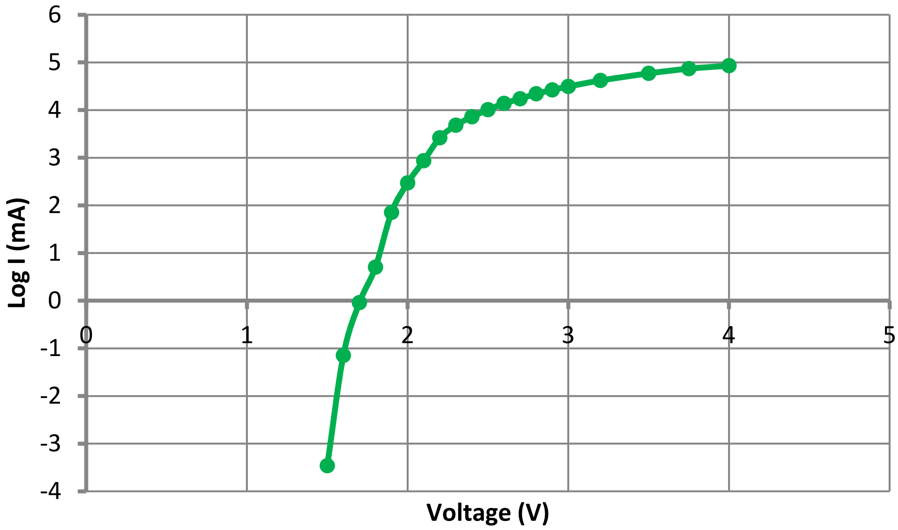


Fig.15: Green LED 3 mm - Log I vs. Voltage.

The Log I vs. Voltage graph above clearly show that the green LED has a parasitic series resistance.

1.5.4 Green LED 5 mm.

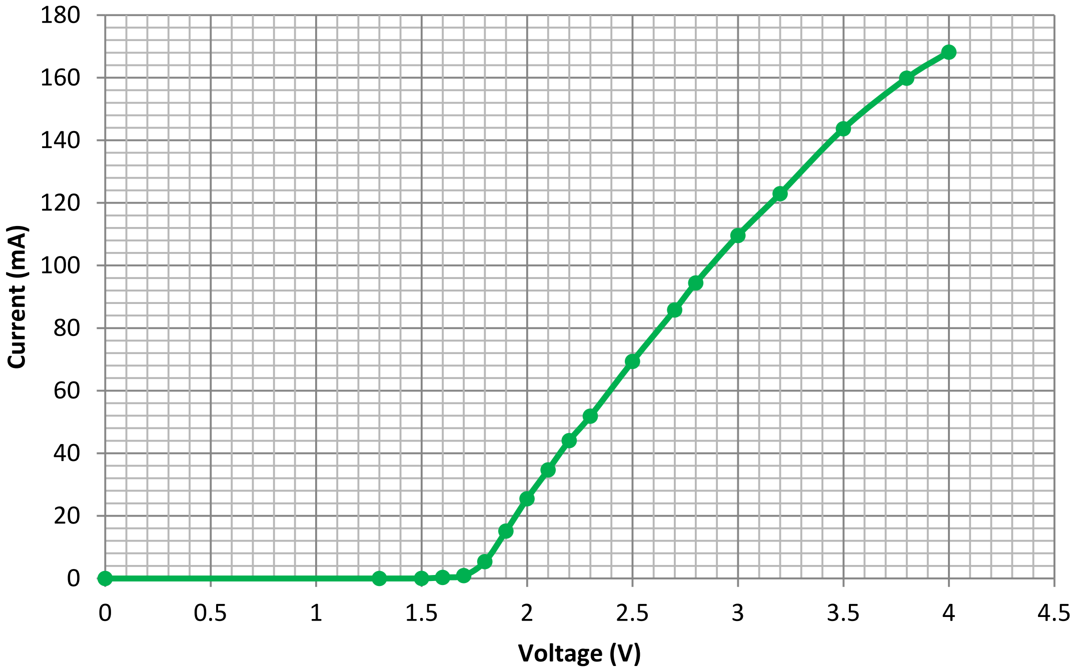


Fig.16: Green LED 5 mm - I-V Characteristic.

In this device, voltages below 1.8 V draw almost no current. The threshold voltage for the green LED 5 mm is approximately 2.1 V.

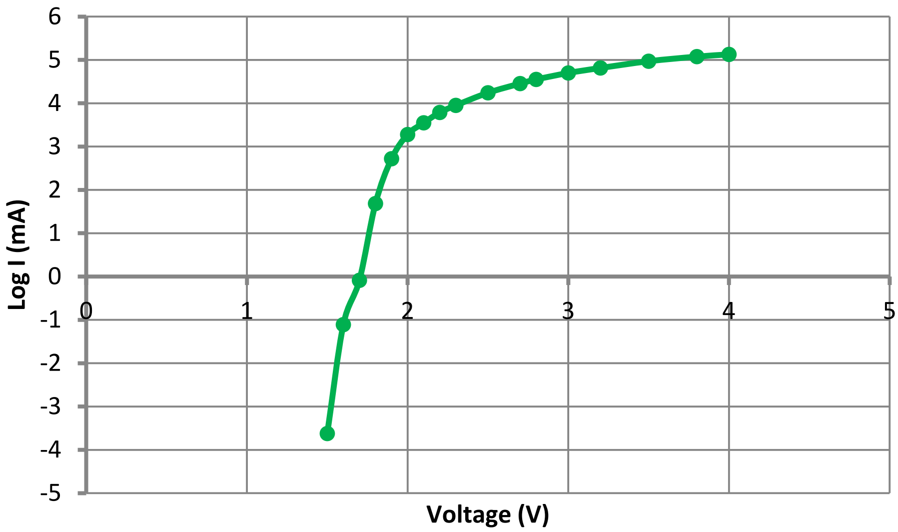


Fig.17: Green LED 5 mm - Log I vs. Voltage.

As we can see in the logarithmic plot of the I-V characteristic, the green LED 5 mm seems to have a series resistance.

1.5.5 Red LED 3 mm.

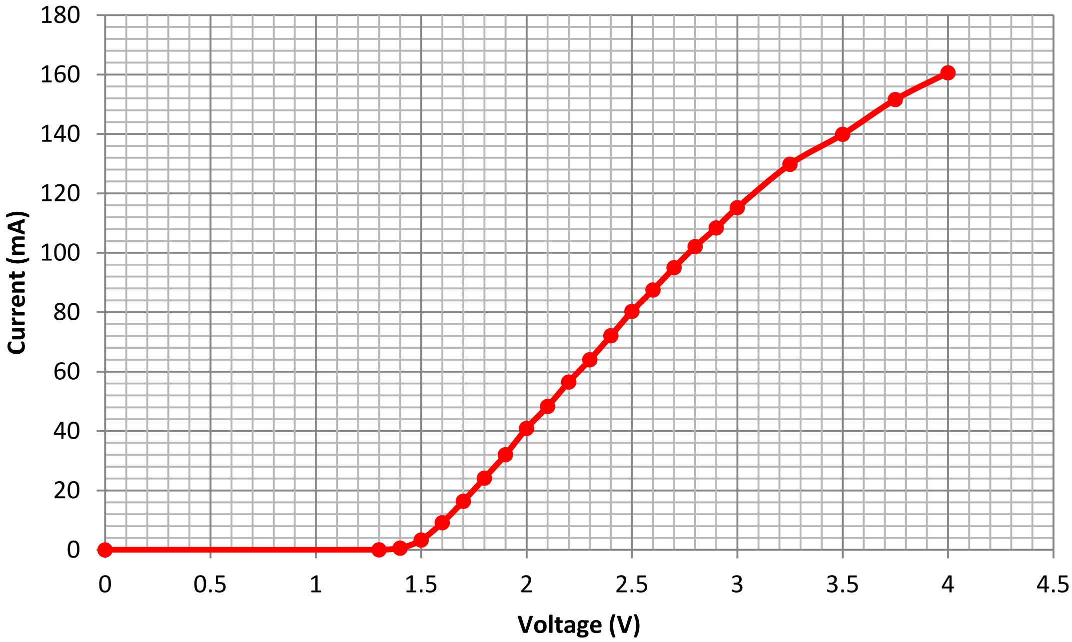


Fig.18: Red LED 3 mm - I-V Characteristic.

For the red LED 3 mm, there is almost no current for voltages below 1.5 V and the threshold voltage is about 1.8 V.

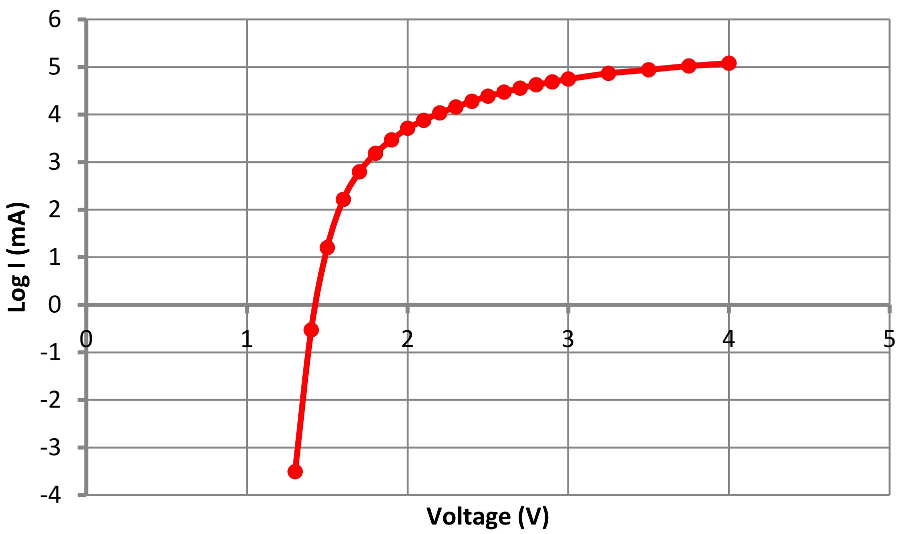


Fig.19: Red LED 3 mm - Log I vs. Voltage.

In this case, the Log I vs. Voltage graph shows that the deviation from the ideal I-V characteristic of the red LED 3mm can be caused by a series resistance.

1.5.6 Red LED 5 mm.

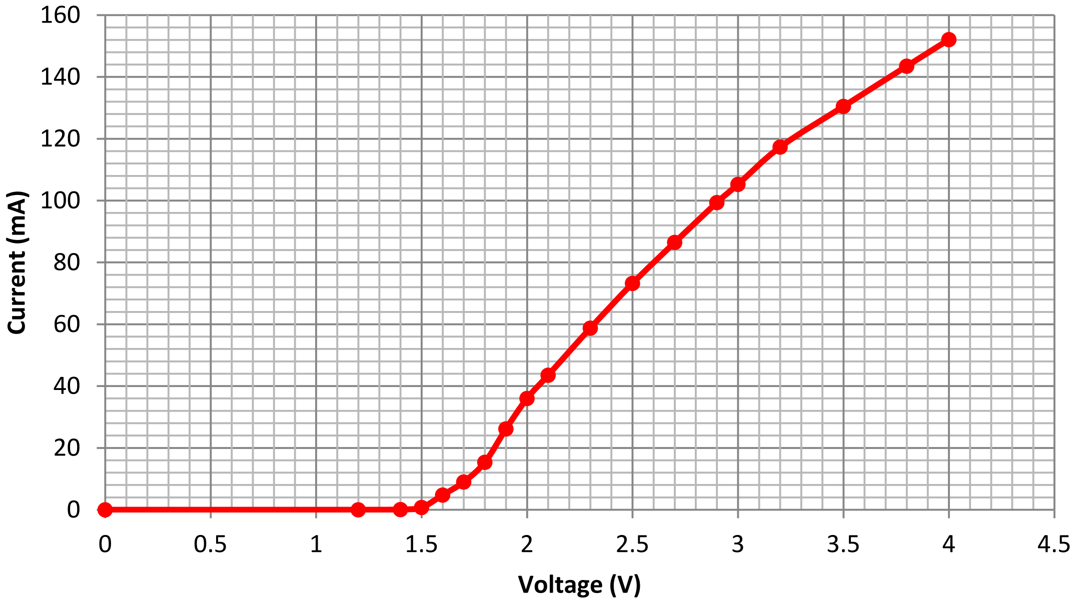


Fig.20: Red LED 5 mm - I-V Characteristic.

For the red LED 5 mm, voltages under 1.5 V draw no current and the turn on voltage is reached at about 1.9 V.

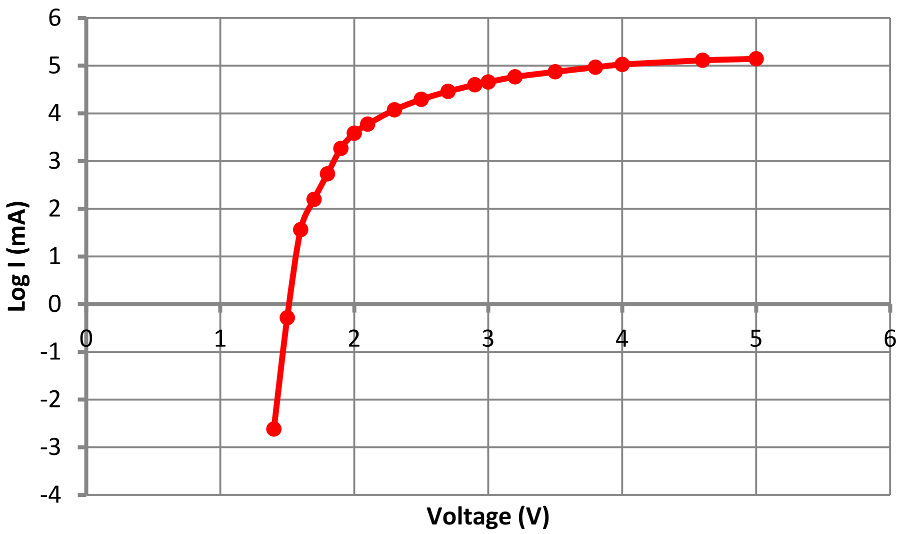


Fig.21: Red LED 5 mm - Log I vs. Voltage.

The I-V curve in a logarithmic scale shows that this device presents a parasitic series resistance.

1.5.7 White LED 3 mm.

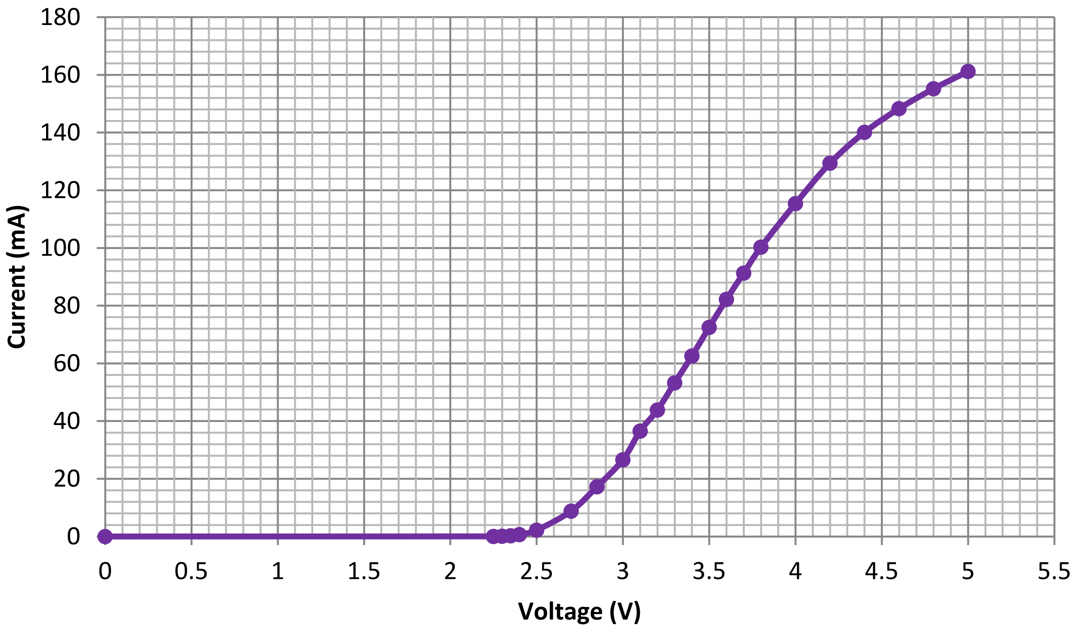


Fig.22: White LED 3 mm - I-V Characteristic.

For the white LED 3mm, we can see in the I-V characteristic that the threshold voltage corresponds to about 3.2 V.

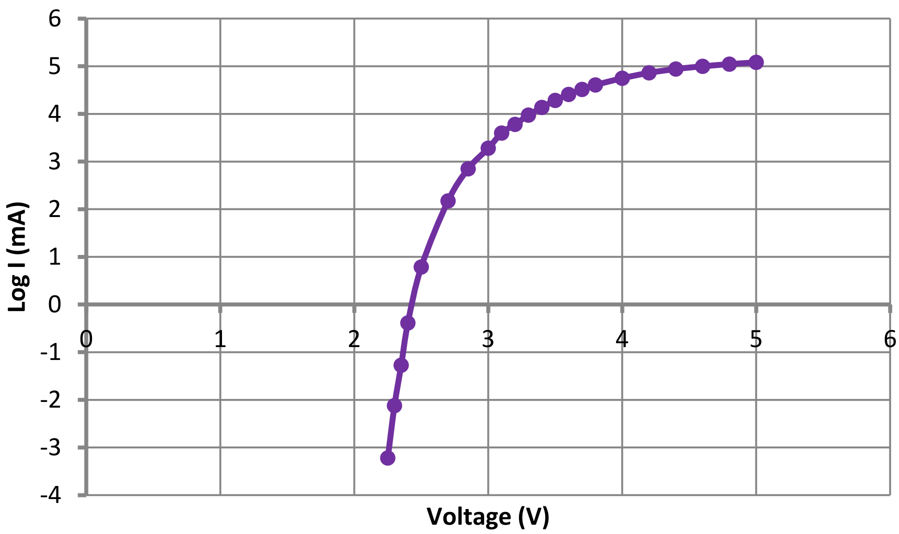


Fig.23: White LED 3 mm - Log I vs. Voltage.

For the white LED 3mm, the deviation observed from the ideal I-V characteristic is caused by a series parasitic resistance.

1.5.8 White LED 5 mm.

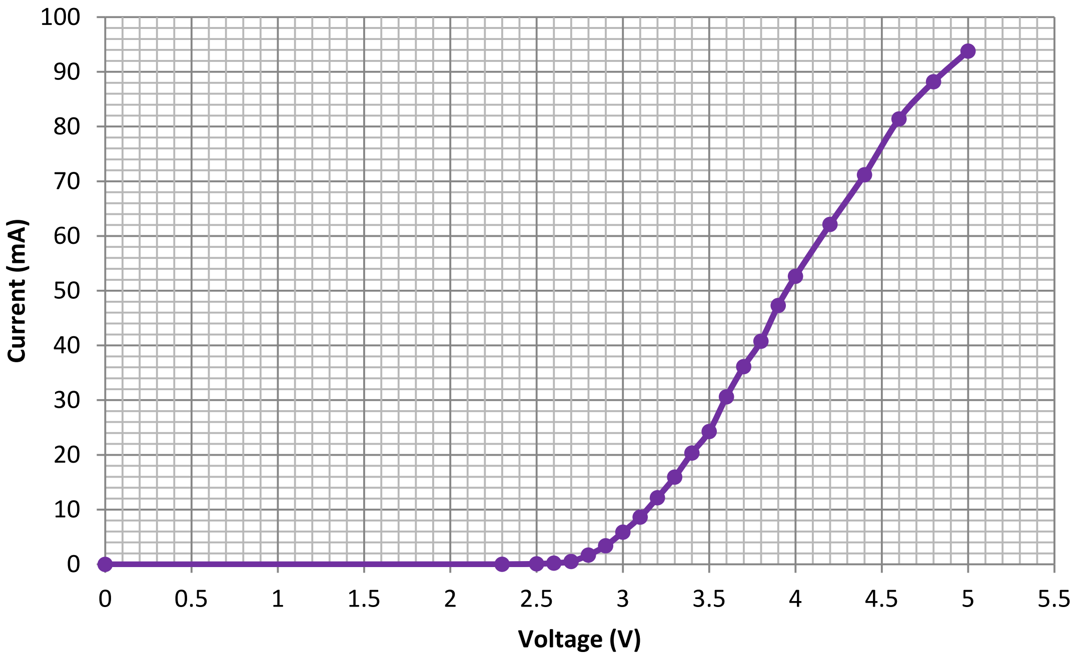


Fig.24: White LED 5 mm - I-V Characteristic.

In this case, we can notice from the graph that the threshold voltage for the white LED 3 mm is 3.4 V.

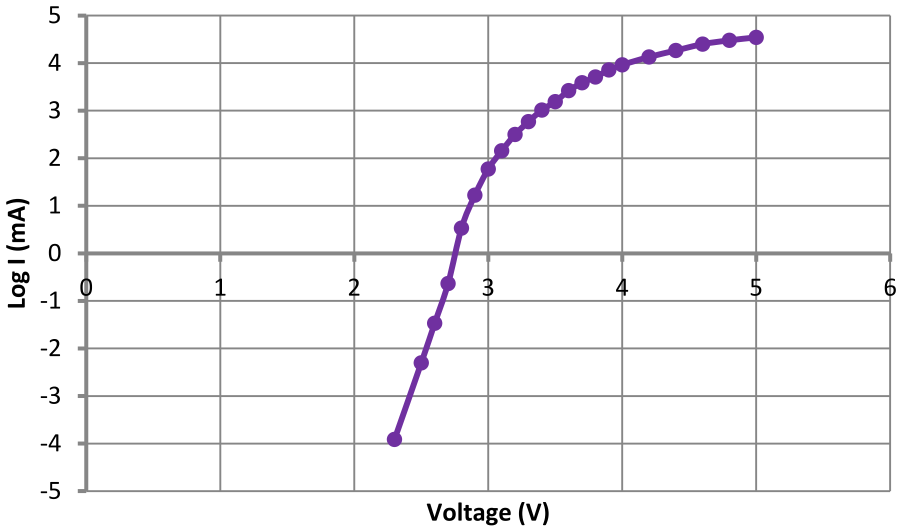


Fig.25: White LED 5 mm - Log I vs. Voltage.

The non-ideal characteristic of the white LED 5 mm is produced by a parasitic series resistance.

1.6 Conclusions.

The following table contains a summary of the results obtained from the I-V characteristics of the LEDs:

LED Colour	Diameter	Measured threshold voltage	Deviation observed
Red	3 mm	1.8 V	Series resistance
Red	5 mm	1.9 V	Series resistance
Green	3 mm	2.1 V	Series resistance
Green	5 mm	2.1 V	Series resistance
Blue	3 mm	3.2 V	Series resistance
Blue	5 mm	4.1 V	Series resistance
White	3 mm	3.2 V	Series resistance
White	5 mm	3.4 V	Series resistance

1) As expected, the turn on voltages of the measured LEDs are slightly different for each colour. The device which has a higher turn on voltage is the blue LED 5 mm (4.1 V) while the red LED 3 mm has the lower turn on voltage (1.8 V).

2) The turn on voltage increases as we move from red toward blue in the visible light spectrum.

3) The logarithmic plots of the I-V characteristics for all the devices show that all the LEDs seem to have a parasitic series resistance. A suggestion for further work about this could be to make an evaluation of the parasitic LED resistance.

2. Spectra Measurements.

2.1 Introduction.

[9, 17, 27] In the output spectrum of an LED, the most important parameter is the peak wavelength, which determines the colour of the LED. Also, one can measure the linewidth (Δλ) of the output spectrum, which is defined as the width between the half intensity points. Sometimes it is also referred as Full Width at Half Maximum (FWHM). The linewidth of an LED emitting in the visible range is relatively narrower than the range of the entire visible spectrum. The LED emission is even narrower than the spectral width of a single colour as perceived by the human eye. For example, red colours range in wavelength are between 610 nm-760 nm, which is much wider than the typical emission of an LED, so the human eye perceive the LED emission as monochromatic. A typical output spectrum (relative intensity vs. wavelength) from a LED is shown below:

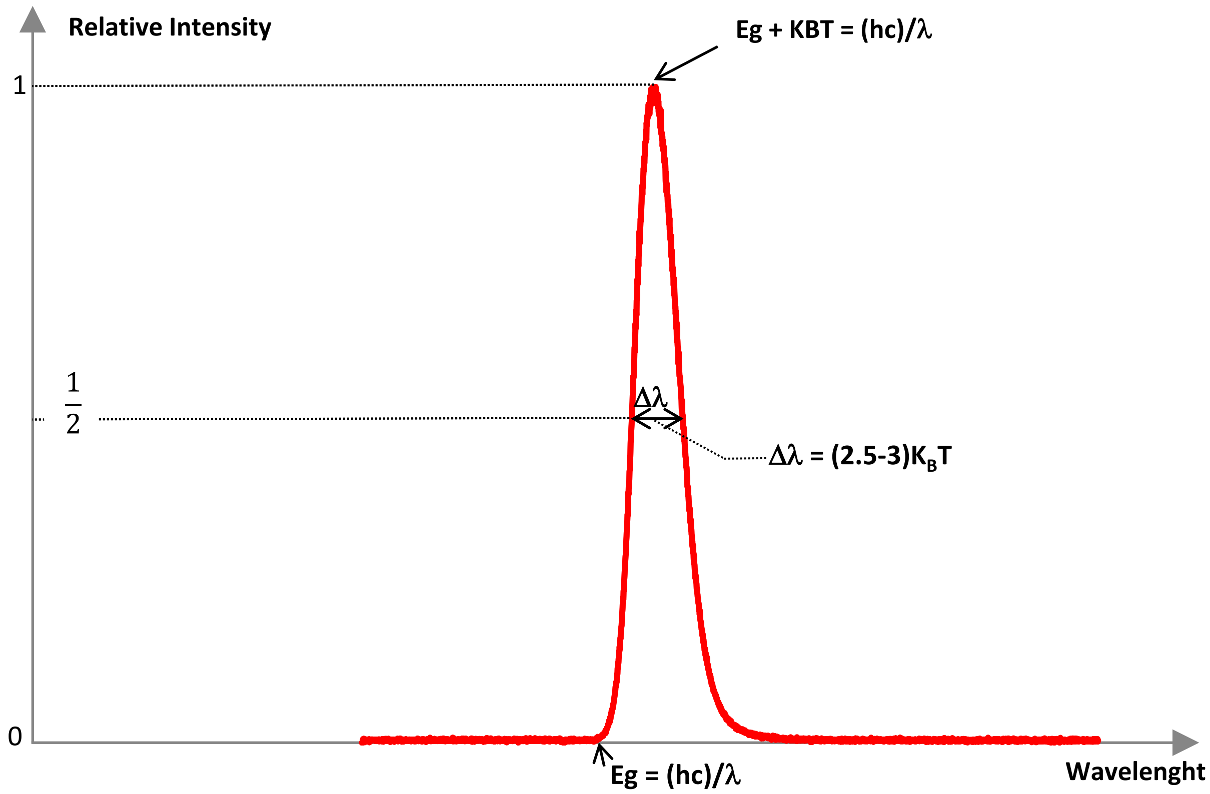


Fig.26:Typical output spectrum of an LED.

The wavelength of the light emitted and therefore the colour of the LED depends on the bandgap energy of the semiconductors of which LEDs are made, so the desired emission wavelength can be achieved by choosing a semiconductor material with an adequate bandgap energy. The wavelength of the light emitted by the LED is inversely proportional to the bandgap energy; the bigger the wavelength the smaller the energy. We can determine the forbidden energy gap of an emitted photon from an LED with the following relation:

$$E_g = h\nu = \frac{hc}{\lambda}$$

Where:

"h" is Planck's constant $h = 6.62 \times 10^{-34} J \cdot s$
"c" the speed of light is vacuum $c = 3 \times 10^{8} \frac{m}{s}$
"λ" is the wavelength, usually in nm.

The photon energy for the peak emission is $E_g + K_B T$ and the linewidth is typically between $2.5 K_B T$ to $3 K_B T$. (K_B is Boltzmann constant, which value is $1.38 \times 10^{-23} \frac{J}{K}$), although these values can vary depending on the LED structure. We can therefore calculate the theoretical linewidth in the output spectrum of a LED as follows:

$$\lambda = \frac{c}{\nu} = \frac{h \cdot c}{E_{photon}}$$

If we differentiate λ respect to the photon energy E_{photon} we get

$$\frac{d\lambda}{dE_{photon}} = -\frac{h \cdot c}{E_{photon}^2}$$

We can represent small intervals by differentials,

$$\Delta\lambda / \Delta E_{photon} \cong |d\lambda / dE_{photon}|$$

Then

$$\Delta\lambda \cong \frac{h \cdot c}{E_{photon}^2} \Delta E_{photon}$$

Considering that the energy width of the output spectrum of a LED is about $3K_BT$.

$$\Delta E_{photon} = \Delta h\nu \cong 3K_BT$$

Thus, substituting we get that:

$$\Delta\lambda = \lambda^2 \frac{3\, K_B T}{h \cdot c}$$

The semiconductors used for the fabrication of visible LEDs must have at least a bandgap of 1.6 eV (spectral range of visible light is from about 380-780 nm i.e from about 3.2 eV to 1.6 eV).

2.2 Motivation.

-To investigate the spectral emission properties of several LEDs.

-To determine the peak wavelength, the linewidth and estimate the bandgap energy for the semiconductor materials of the different LEDs. Compare the measured results with the theoretical values.

2.3 Equipment needed.

-DC power supply.
-LEDs.
-Spectrometer.
-Computer (SpectraSuite software).

2.4 Setup.

The main item of equipment for this experiment is a spectrometer interfaced to a PC, which displays the intensity of light as a function of wavelength in the screen. The program that displays the output spectrum is called SpectraSuite. The sensitivity can be changed by adjusting the integration time. The LED is turned on with a forward bias current of $\mathrm{I_F} = 20\ \mathrm{mA}$ provided by a DC power supply and the output light is detected by the spectrometer. Fig. Shows a schematic diagram of the setup for the experiment and in Fig. we can see some photos taken during the experiment.

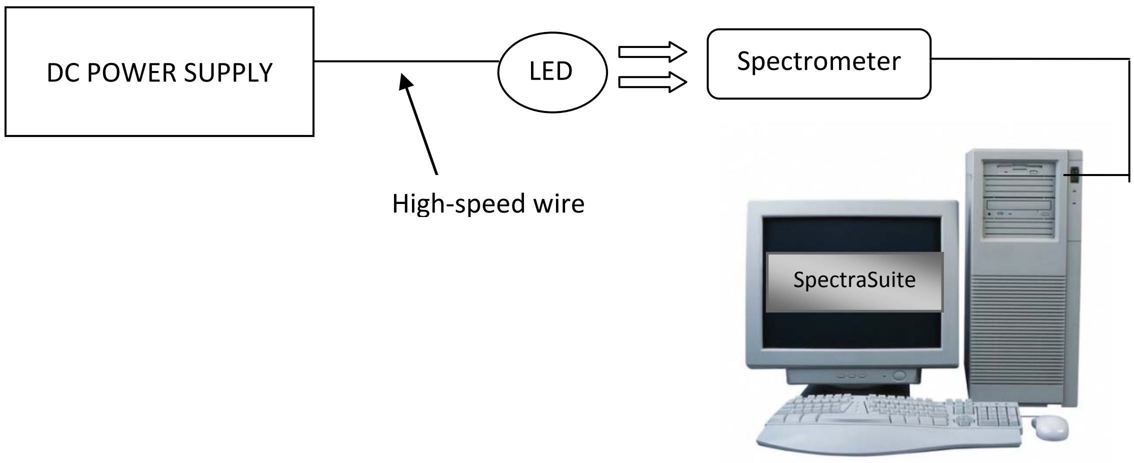
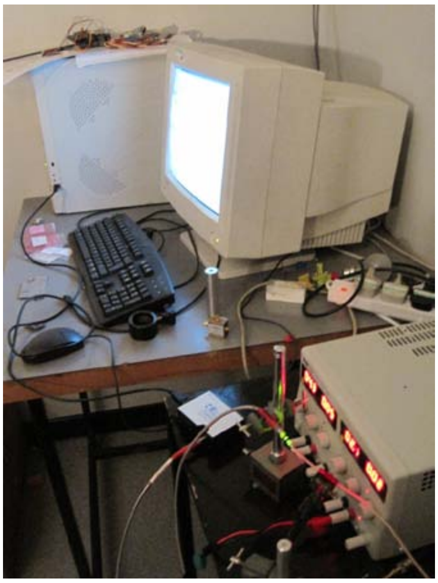
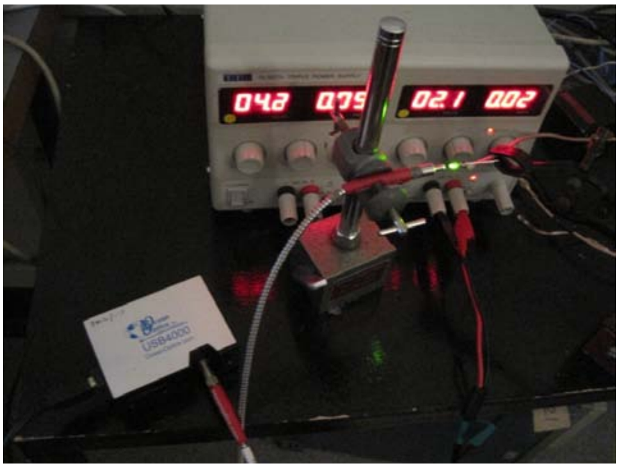


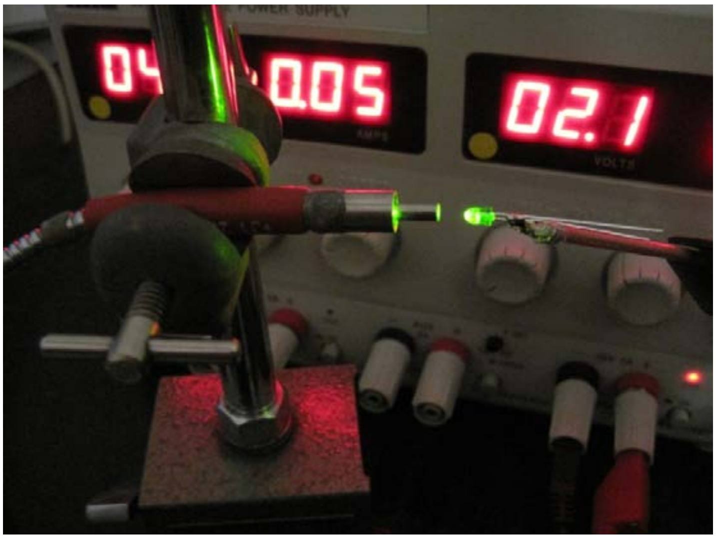
Fig.27: Block diagram for the LEDs spectra measurements.



(a)



(b)



(c)

Fig.28: (a) DC power supply, LED and spectrometer interfaced to a PC. (b) DC Power supply, LED and spectrometer. (c) The output light of the LED is detected by the spectrometer.

2.5 Results.

Note that all LEDs were switched on with the same forward current of $I_F = 20\ \text{mA}$.

2.5.1 Blue LED 3 mm.

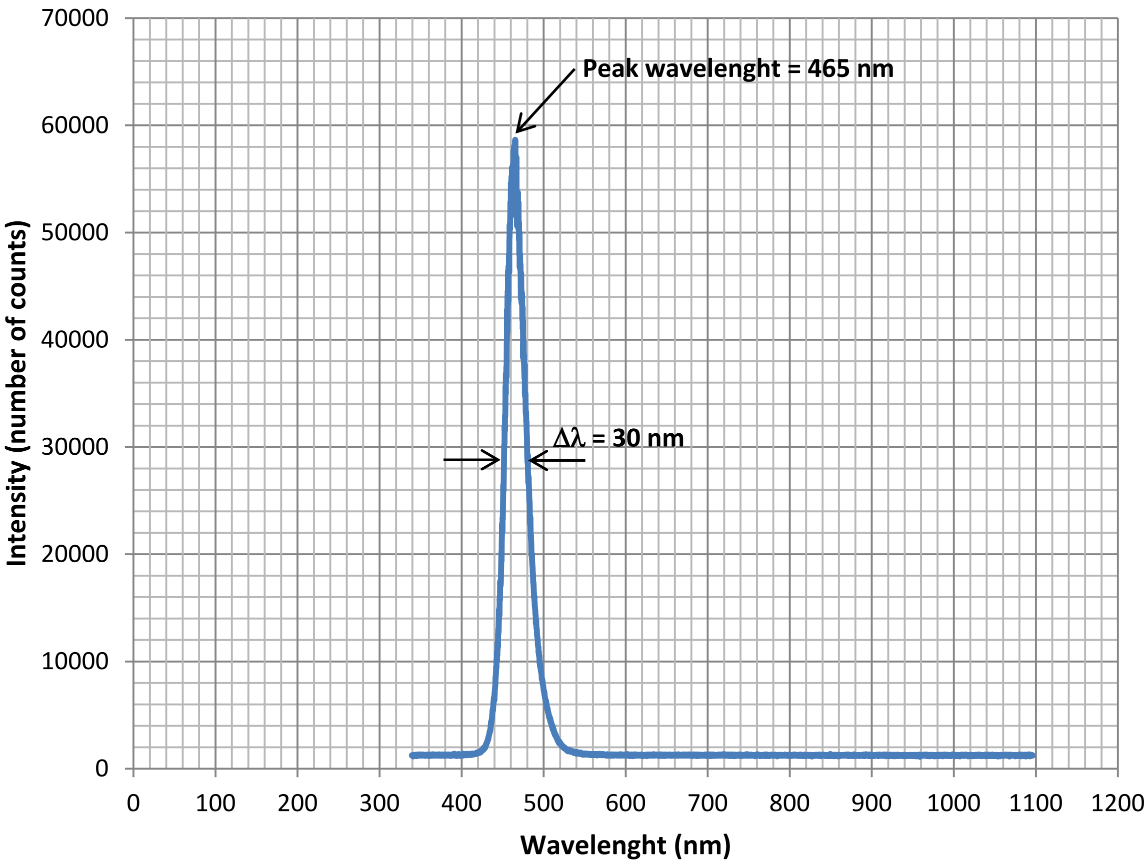


Fig.29: Blue LED 3 mm Spectrum.

The peak wavelength is about 465 nm and the FWHM or linewidth equals to 30 nm. Looking at the datasheet we can see that this blue LED is made with Indium Gallium Nitride (InGaN). The wavelength at which the LED starts to transmit optical energy is about 430 nm. Thus, we can calculate the bandgap energy of the semiconductor using the formula stated above:

$$E_g = h\upsilon = \frac{h \cdot c}{\lambda} = \frac{6.62 \times 10^{-34} \text{J} \cdot \text{s} \cdot 3 \times 10^{8}\ {}^{\text{m}}/_{\text{s}}}{430\ \text{nm}} = 4.618 \times 10^{-19} \text{J} = 2.886\ \text{eV}$$

The theoretical linewidth for this LED can also be calculated from the equation above (considering that the room temperature is T=300 K):

$$\Delta\lambda = \lambda^2 \frac{3\ K_B T}{h\ c} = (465\text{nm})^2 \frac{3 \cdot 1.38 \times 10^{-23} \text{J/K} \cdot 300\ \text{K}}{6.64 \times 10^{-34}\ \text{J} \cdot \text{s} \cdot 3 \times 10^{8}\ \text{m/s}} = 13.48\ \text{nm}$$

The theoretical linewidth is much narrower than the measured result. The experimentally determined linewidth corresponds to 6.67 $K_B T$.

2.5.2 Blue LED 5 mm.

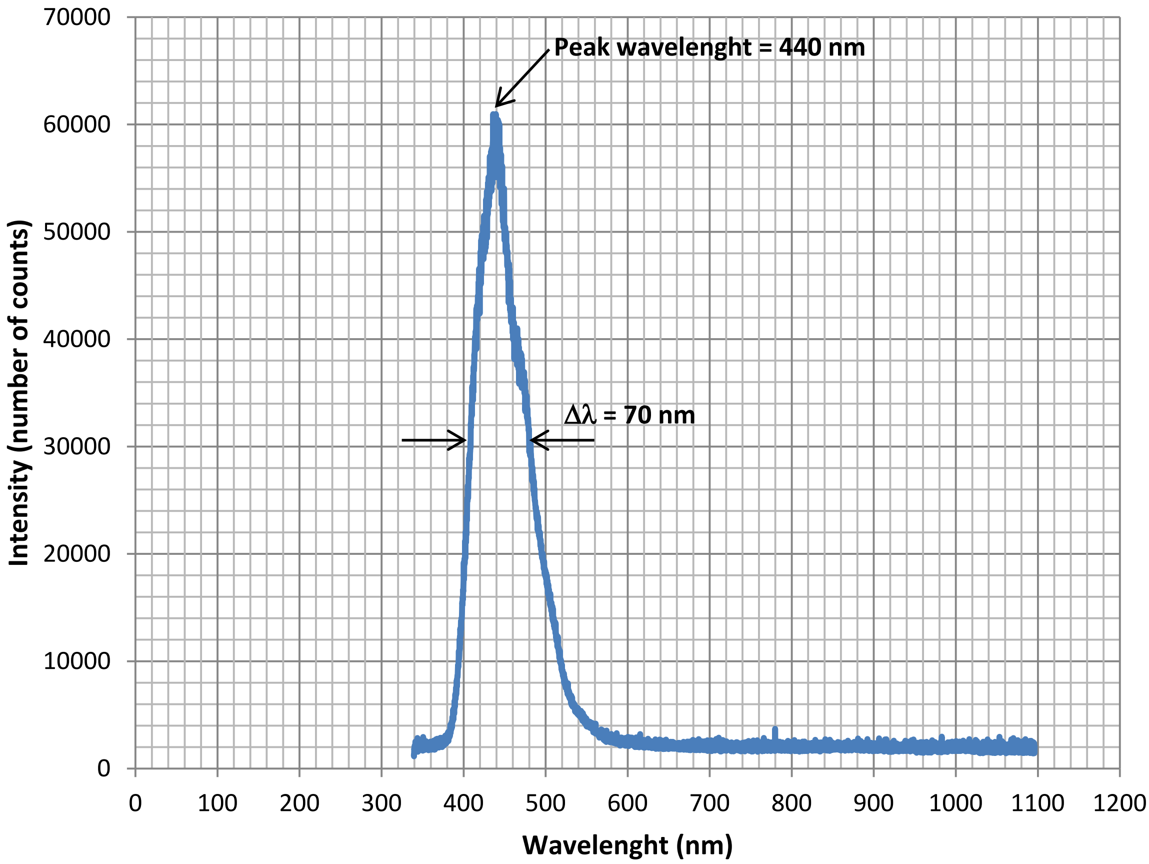


Fig.30: Blue LED 5 mm Spectrum.

The peak wavelength corresponds to 440 nm and the linewidth is 70 nm. This device is made of Gallium Nitride (GaN), so again we can calculate the bandgap of the semiconductor:

$$E_g = h\upsilon = \frac{h \cdot c}{\lambda} = \frac{6.62 \times 10^{-34} \mathrm{J} \cdot \mathrm{s} \cdot 3 \times 10^{8}\, {}^{\mathrm{m}}/_{\mathrm{s}}}{380\ \mathrm{nm}} = 5.226 \times 10^{-19} \mathrm{J} = 3.266\ \mathrm{eV}$$

The theoretical linewidth for this LED is calculated below (for T=300K):

$$\Delta\lambda = \lambda^2 \frac{3\, K_B T}{h\, c} = (440\mathrm{nm})^2 \frac{3 \cdot 1.38 \times 10^{-23} \mathrm{J/K}\ \cdot 300\ \mathrm{K}}{6.64 \times 10^{-34}\ \mathrm{J} \cdot \mathrm{s}\ \cdot 3 \times 10^{8}\ \mathrm{m/s}} = 12.07\ \mathrm{nm}$$

As we can see, the theoretical linewidth is much smaller than the measured linewidth. The experimentally determined linewidth corresponds to 17.39 $K_B T$.

2.5.3 Green LED 3 mm.

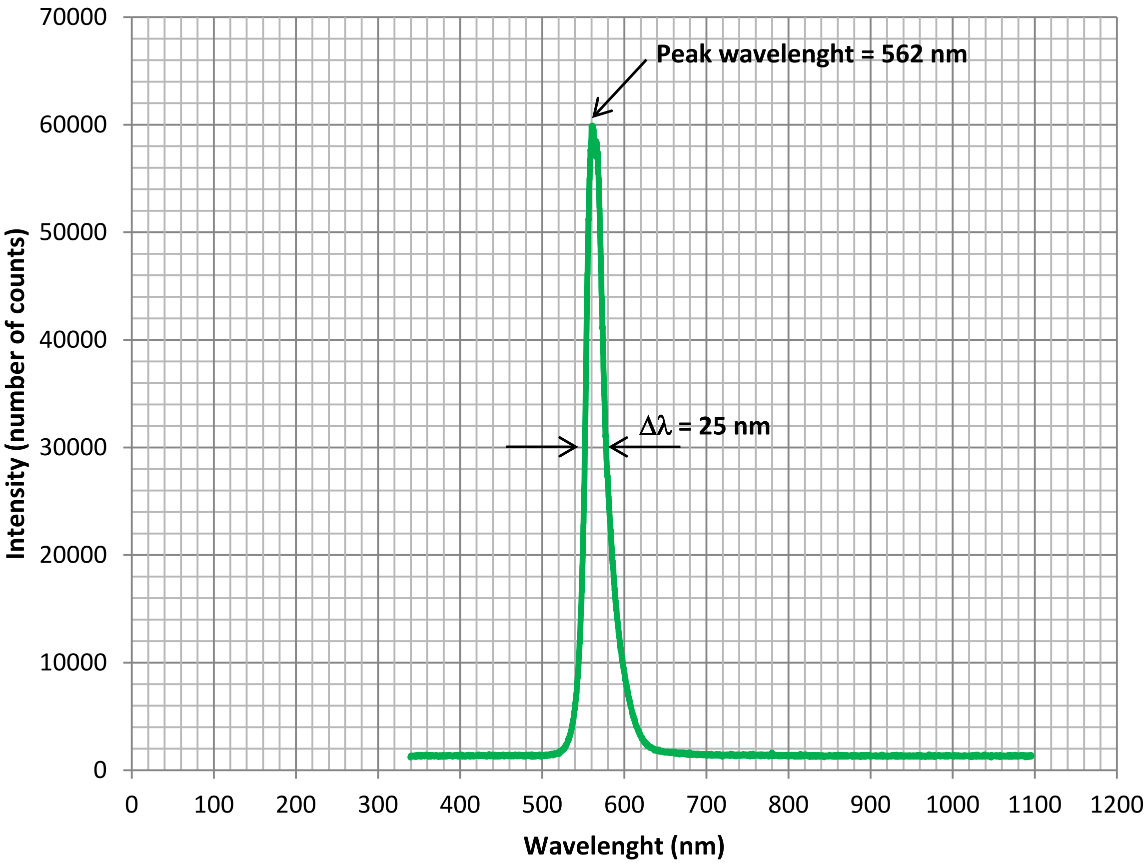


Fig.31: Green LED 3 mm Spectrum.

The wavelength for the peak intensity is 562 nm and the FWHM is 25 nm. This green colour LED device is made with Gallium Phosphide (GaP). The wavelength at which the green LED 3 mm begins to transmit optical power is about 530 nm and the bandgap energy is given by:

$$E_g = h\upsilon = \frac{h \cdot c}{\lambda} = \frac{6.62 \times 10^{-34} J \cdot s \cdot 3 \times 10^8 \, {}^{m}/_{s}}{530 \text{ nm}} = 3.747 \times 10^{-19} J = 2.341 \text{ eV}$$

Considering that the room temperature is T=300 K, the expected linewidth for this LED is given by:

$$\Delta\lambda = \lambda^2 \frac{3 \, K_B T}{h \, c} = (562\text{nm})^2 \frac{3 \cdot 1.38 \times 10^{-23} J/K \; \cdot 300 \text{ K}}{6.64 \times 10^{-34} \, J \cdot s \; \cdot 3 \times 10^8 \text{ m/s}} = 19.69 \text{ nm}$$

In this case, the theoretical linewidth is close the measured linewidth. The experimentally determined linewidth corresponds to 3.8 $K_B T$.

2.5.4 Green LED 5mm.

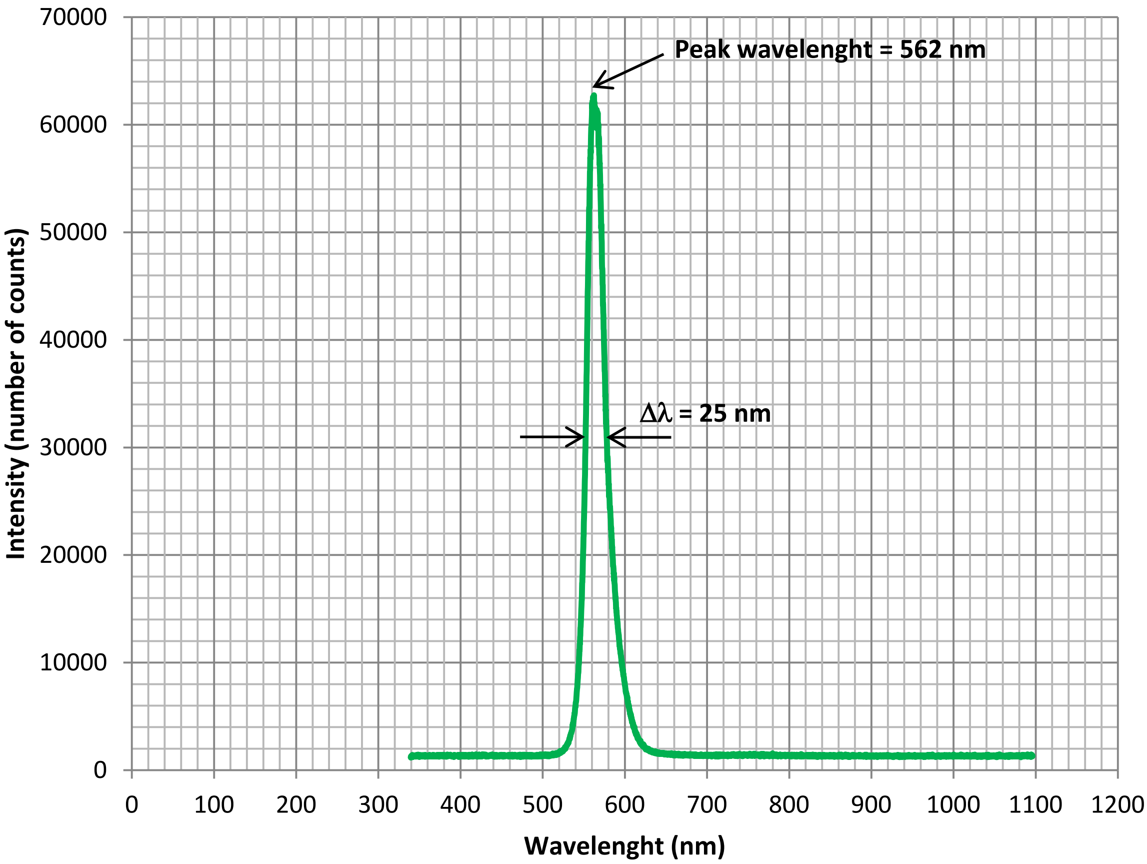


Fig.32: Green LED 5 mm Spectrum.

The peak wavelength and linewidth for the green LED 5mm 562 nm and 25 nm respectively. The semiconductor material from which this LED is made is Gallium Phosphide (GaP) and its bandgap energy is given by:

$$E_g = h\upsilon = \frac{h \cdot c}{\lambda} = \frac{6.62 \times 10^{-34} J \cdot s \cdot 3 \times 10^8 \, {}^{m}/_{s}}{530 \text{ nm}} = 3.747 \times 10^{-19} J = 2.341 \text{ eV}$$

For T=300 K, the theoretical linewidth can be calculated as:

$$\Delta\lambda = \lambda^2 \frac{3 \, K_B T}{h \, c} = (562\text{nm})^2 \frac{3 \cdot 1.38 \times 10^{-23} J/K \ \cdot 300 \text{ K}}{6.64 \times 10^{-34} \, J \cdot s \ \cdot 3 \times 10^8 \text{ m/s}} = 19.69 \text{ nm}$$

The measured result is slightly smaller than the theoretical result. The experimentally determined linewidth corresponds to 3.8 $K_B T$.

2.5.5 Red LED 3 mm

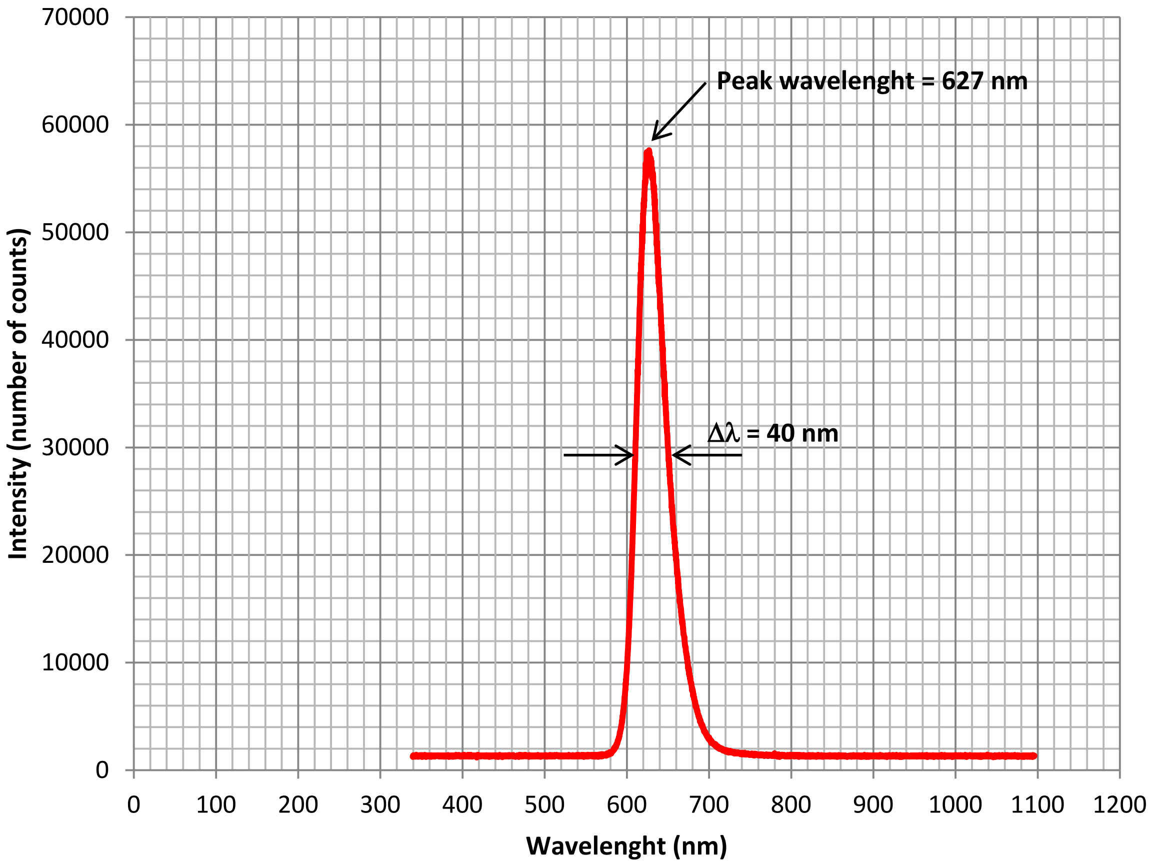


Fig.33: Red LED 3 mm Spectrum.

The peak wavelength is 627 nm and the FWHM is 40 nm. This red LED of 3 mm is made of Gallium Arsenide Phosphide on Gallium Phosphide Orange (GaAsP/GaP). The bandgap energy can be calculated using the formula:

$$E_g = h\upsilon = \frac{h \cdot c}{\lambda} = \frac{6.62 \times 10^{-34} \mathrm{J} \cdot \mathrm{s} \cdot 3 \times 10^{8}\, ^{\mathrm{m}}/_{\mathrm{s}}}{585\ \mathrm{nm}} = 3.394 \times 10^{-19}\mathrm{J} = 2.121\ \mathrm{eV}$$

The theoretical linewidth, for a room temperature T=300 K, is given by:

$$\Delta\lambda = \lambda^2 \frac{3\ K_B T}{h\ c} = (627\ \mathrm{nm})^2 \frac{3 \cdot 1.38 \times 1.38 \times 10^{-23} \mathrm{J/K}\ \cdot 300\ \mathrm{K}}{6.64 \times 10^{-34}\ \mathrm{J} \cdot \mathrm{s}\ \cdot 3 \times 10^{8}\ \mathrm{m/s}} = 24.51\ \mathrm{nm}$$

We can notice that the experimentally determined linewidth is wider than the theoretical result. The measured linewidth corresponds to 4.89 $K_B T$.

2.5.6 Red LED 5 mm.

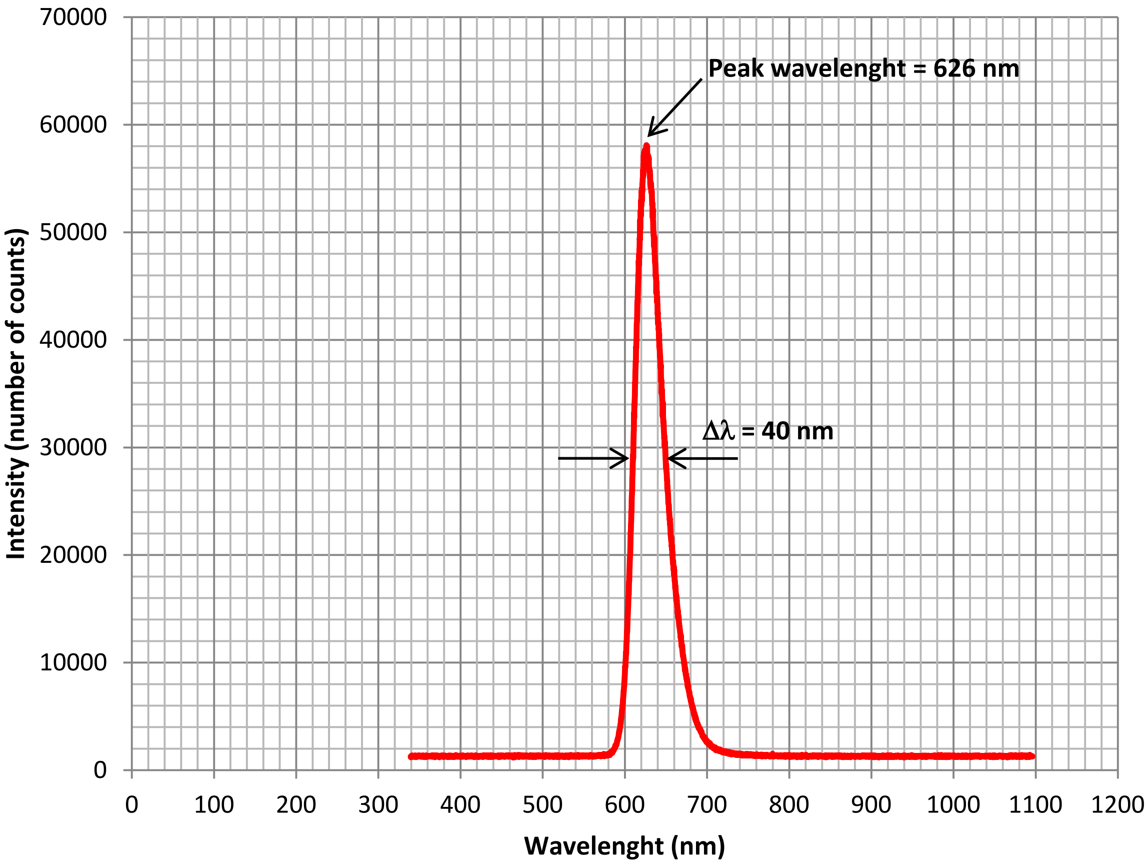


Fig.34: Red LED 5 mm Spectrum.

The peak wavelength corresponds to 626 nm and the linewidht is 40 nm. The semiconductor material from which this LED is made of is GaASP/GaP, and the energy bandgap is calculated below:

$$E_g = h\upsilon = \frac{h \cdot c}{\lambda} = \frac{6.62 \times 10^{-34} J \cdot s \cdot 3 \times 10^8 \, {}^{m}/_{s}}{585 \text{ nm}} = 3.394 \times 10^{-19} J = 2.121 \text{ eV}$$

Assuming that the room temperature was T=300 K, the theoretical linewidht is estimated below:

$$\Delta\lambda = \lambda^2 \frac{3\, K_B T}{h\, c} = (626 \text{ nm})^2 \frac{3 \cdot 1.38 \times 1.38 \times 10^{-23} J/K \cdot 300 \text{ K}}{6.64 \times 10^{-34} \, J \cdot s \cdot 3 \times 10^8 \text{ m/s}} = 24.43 \text{ nm}$$

As we can see, the measured linewidth is narrower than the theoretical value calculated above. The experimentally determined linewidth corresponds to 4.91 $K_B T$.

2.5.7 White LED 3 mm.

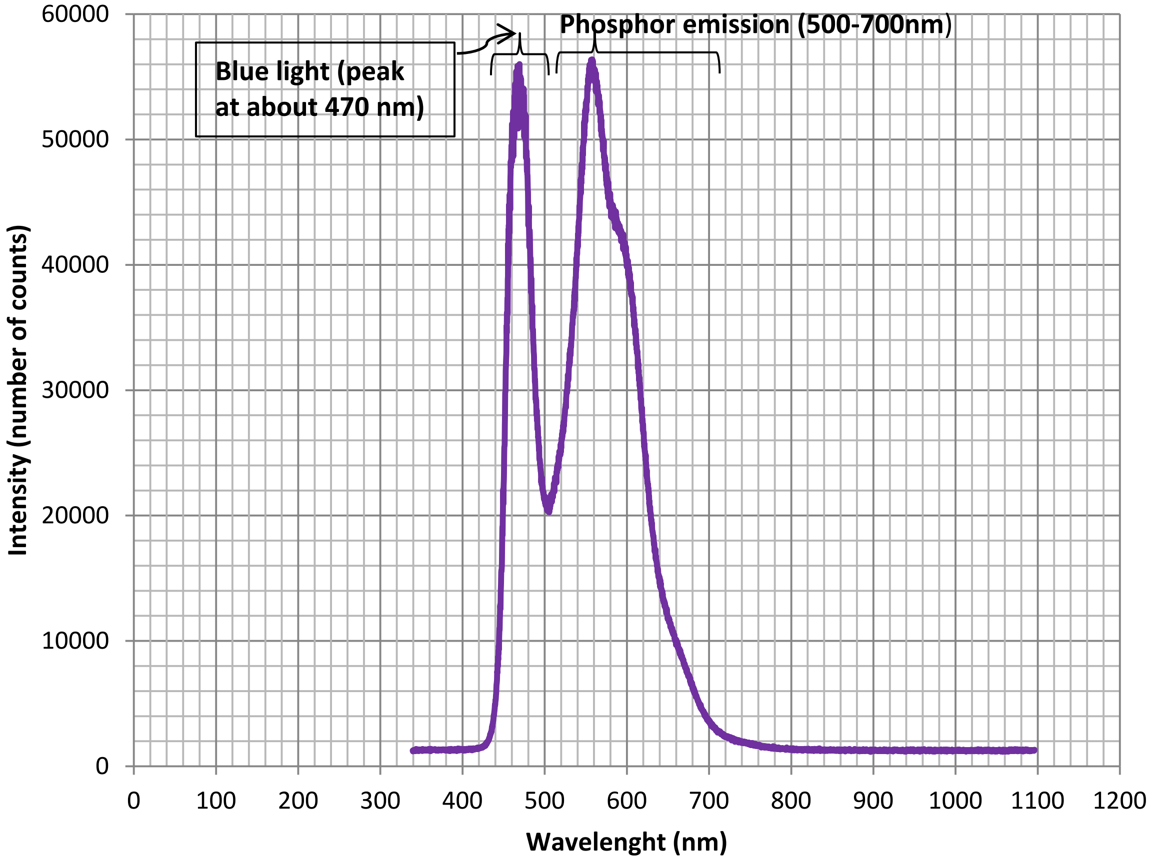


Fig.35: White LED 3 mm Spectrum.

To form white light, this white-light emitter device uses an LED emitting at a short wavelength (e.g. blue) and a wavelength converter (e.g. phosphor). A fraction of the blue light is absorbed by the phosphor and re-emitted as longer wavelength light.

The emission spectrum of this LED consists of the blue emission (peak at about 470 nm and linewidth of 38 nm) and a broader spectrum from 500 nm to 700 nm emitted by the phosphor that has a peak emission wavelength of 556 nm and a full width at half maximum of 94 nm.

The wavelength conversion efficiency is an important parameter in phosphor-based LEDs, and it can be calculated as follows:

$$\eta_{\lambda-conversion} = \frac{\lambda_1}{\lambda_2} \times 100$$

Where λ_1 is the wavelength absorbed by the phosphor and λ_2 is the wavelength emitted by the phosphor.

In our previous spectrum of the white LED 3 mm, the wavelength conversion efficiency of the device is:

$$\eta_{\lambda-conversion} = \frac{\lambda_1}{\lambda_2} \times 100 = \frac{470\ nm}{556\ nm} \times 100 = 84.53\%$$

2.5.8 White LED 5 mm.

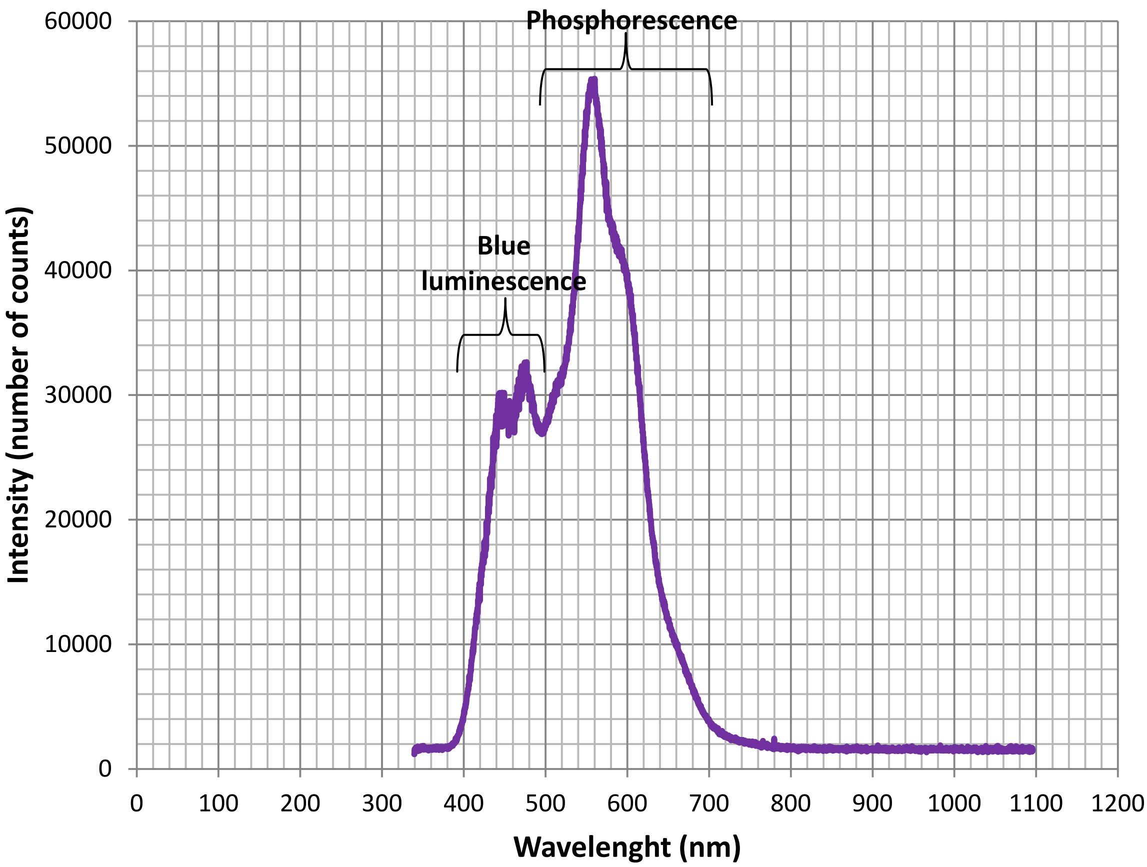


Fig.36: White LED 5 mm Spectrum.

The emission spectrum of the phosphor-based white LED 5 mm spectrum consists of a blue luminescence (peak at about 470 nm) and longer wavelength phosphorescence (from about 500 nm to 700 nm and peak at 560 nm). We can therefore calculate the wavelength conversion efficiency as the previous spectrum:

$$\eta_{\lambda-conversion} = \frac{\lambda_1}{\lambda_2} \times 100 = \frac{470\ nm}{560\ nm} \times 100 = 83.9\%$$

2.6 Conclusions.

The following table contains a summary of the results obtained:

LED Colour	Diameter	λpeak	Eg semiconductor	Δλ
Blue	3 mm	465 nm	2.886 eV	30 nm
Blue	5 mm	440 nm	3.266 eV	70 nm
Green	3 mm	562 nm	2.341 eV	25 nm
Green	5 mm	562 nm	2.341 eV	25 nm
Red	3 mm	627 nm	2.121 eV	40 nm
Red	5 mm	626 nm	2.121 eV	40 nm
White	3 mm	Broad spectrum	-	-
White	5 mm	Broad spectrum	-	-

1) The peak wavelengths of the LEDs are as expected and thus the results obtained did not have discrepancies with theory. The table below shows the colours of the LEDs with typical wavelength ranges:

Colour	λ (nm)
Blue	$440<\lambda<500$
Green	$500<\lambda<570$
Red	$610<\lambda<760$
White	Broad spectrum

As we can notice, the measured wavelengths are inside the range of the typical wavelength values, and for the white LEDs the broad spectrum formed was shown.

2) The blue LED 5 mm linewidht is particularly broad (70 nm). The devices with the narrower FWHM are the green LEDs both of 3 mm and 5 mm.

3) The experimentally determined linewidths differ from the theoretical values (see the table below).

LED Colour	Diameter	Δλ (measured)	Δλ (theoretical)
Blue	3 mm	30 nm	13.48 nm
Blue	5 mm	70 nm	12.07 nm
Green	3 mm	25 nm	19.69 nm
Green	5 mm	25 nm	19.69 nm
Red	3 mm	40 nm	24.51 nm
Red	5 mm	40 nm	24.43 nm
White	3 mm	-	-
White	5 mm	-	-

4) By way of illustration, the bandgap energy of the semiconductor material GaP at room temperature is 2.26 eV, and for GaN is 3.425 eV. This shows that our estimation of the bandgap energy of the LEDs semiconductor materials is similar to the theoretical values.

5) Regarding to the white LEDs, the wavelength conversion efficiency is relatively high.

3. Light Power vs. Current Characteristics.

3.1 Introduction.

[9, 17, 47] The Output Light Power vs. Current characteristic is a very important characteristic of an LED. The increase in the output light power is not linear with the LED current; surface-emitting LEDs with a small light-emitting diameter tend to have sublinear L-I characteristics. At high current levels, strong injection of carriers leads to saturation. A typical output light power vs. forward current of an LED is shown below.

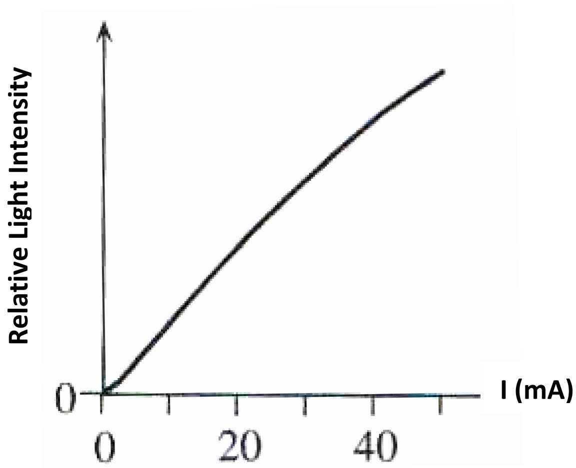


Fig.37: Typical Output Light Power vs. Current Characteristic of an LED.

3.2 Motivation.

The aim of this experiment is to measure the Light Power vs. Current (L-I) characteristic of different LEDs.

3.3 Equipment required.

-LEDs.
-DC power supply.
-Digital multimeter.
-Optical Power Meter.

3.4 Setup.

The LED is switched on through a high-speed cable with a bias current provided by a DC power supply. The output power of the LED is detected by an optical power meter and we take pair of readings of Output Power-Current to plot the results later.

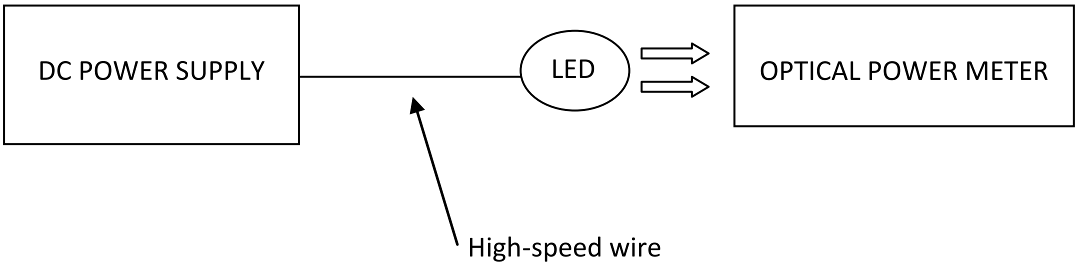


Fig.38: Block diagram of the setup for the L-I Characteristics experiment.

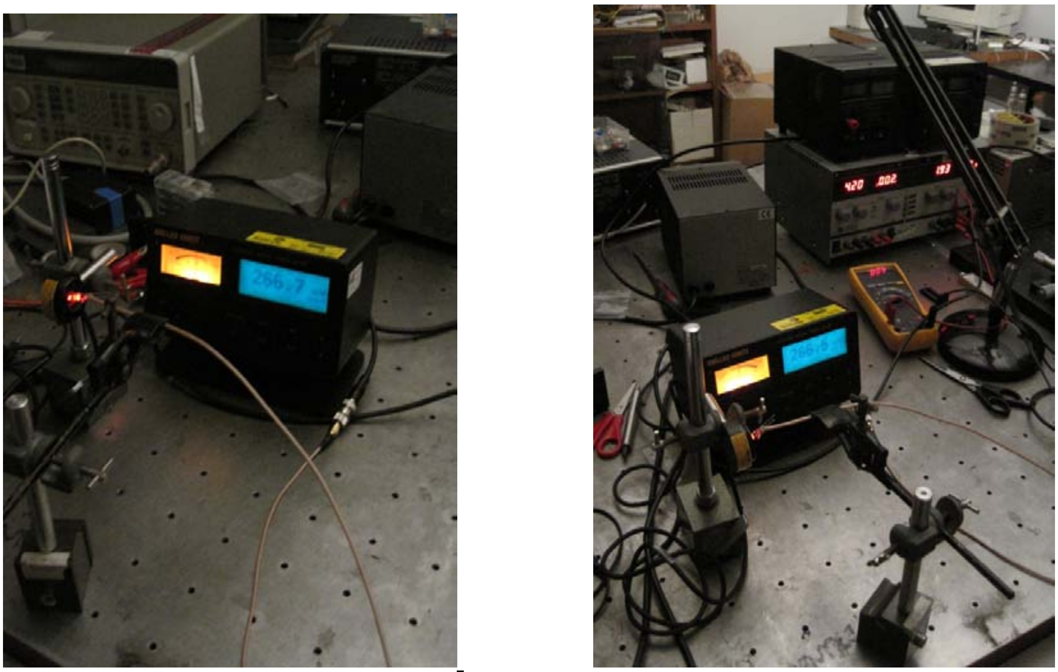


Fig.39: Pictures taken during the experiment. We can see how the LED is switched on with a DC power supply and the output light of the LED is detected by the optical power meter.

3.5 Results.

3.5.1 Blue LED 3 mm.

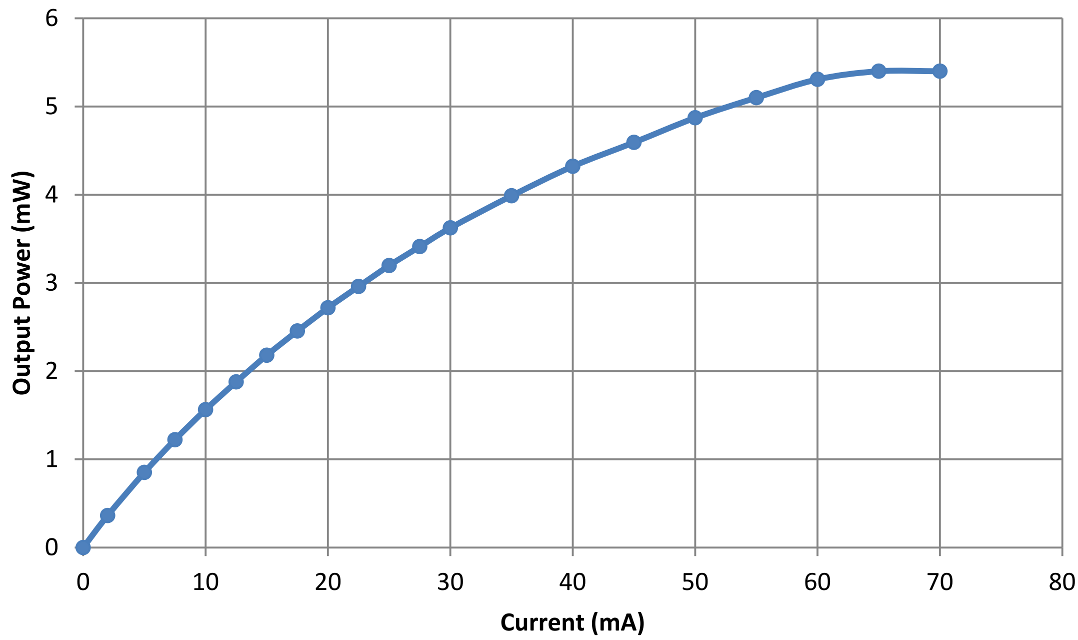


Fig.40: Blue LED 3 mm - Output Power vs. Current.

Above 65 mA, the light intensity seems to have reached a maximum level. Increasing the current over this saturation point has no effect on the light intensity. The maximum output optical power for this LED is 5.4 mW.

3.5.2 Blue LED 5 mm.

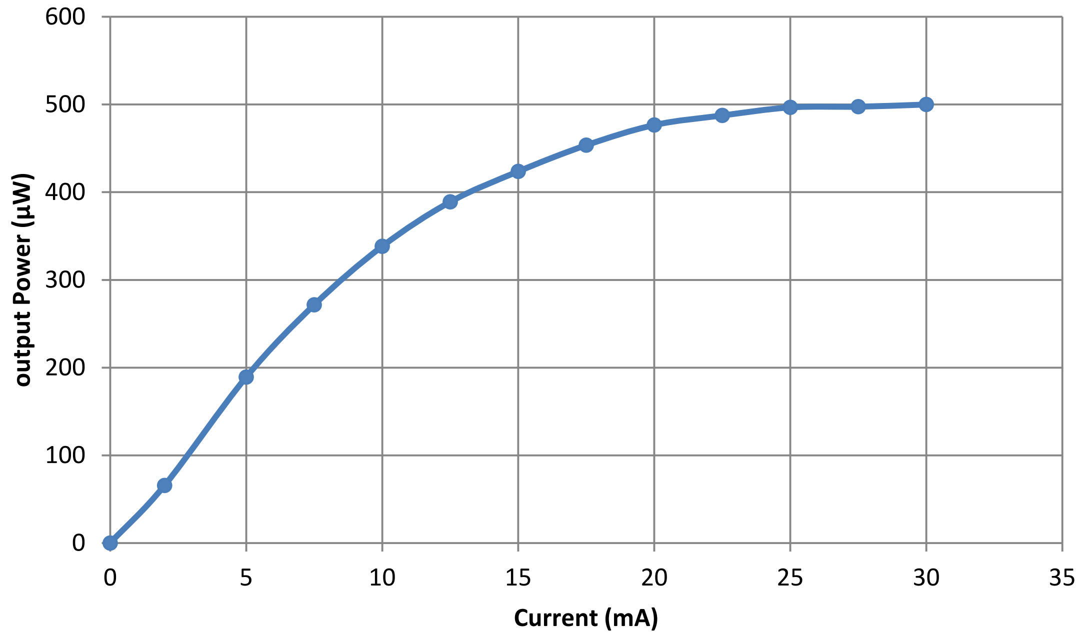


Fig.41: Blue LED 5 mm - Output Power vs. Current.

For the blue LED 5 mm, for larger currents than 30 mA the light intensity remains constant. The maximum output power is 500 μW.

3.5.3 Green LED 3 mm.

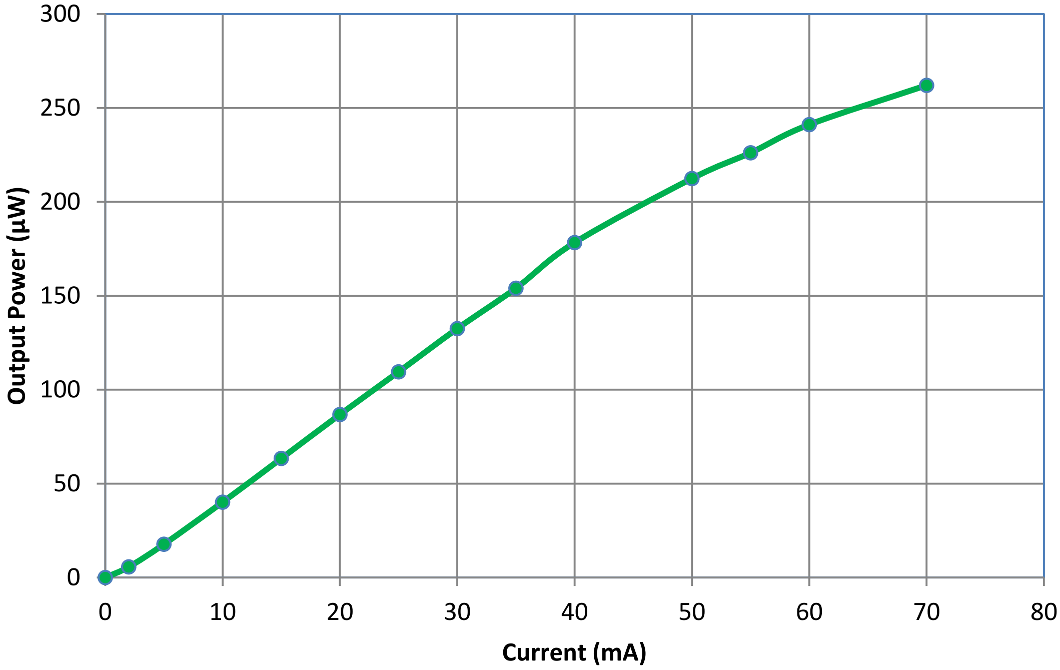


Fig.42: Green LED 5 mm - Output Power vs. Current.

The Light vs. Current characteristic of the green device of 3 mm is shown above. The current through the green LED and the output power seem to be directly proportional for small currents. For larger currents the curve bends over until the saturation point is reached at 70 mA. The maximum output power for the green LED 3 mm is 262 µW.

3.5.4 Green LED 5 mm.

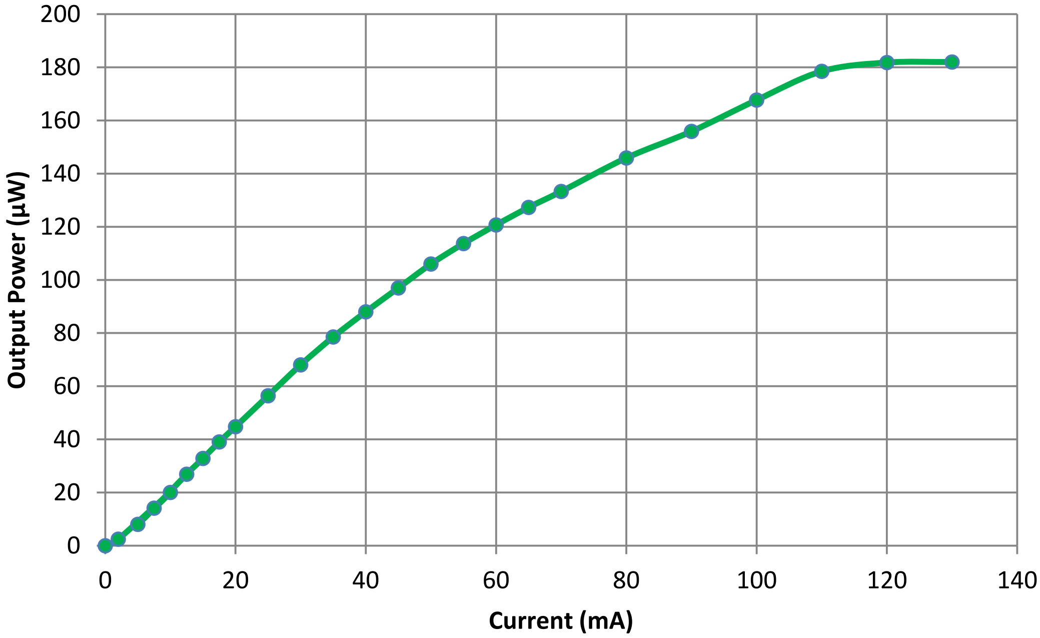


Fig.43: Green LED 5 mm - Output Power vs. Current.

For the green LED 5 mm, the Light-Current characteristic is almost linear for low currents and above 120 mA the saturation point is reached. The maximum output power is 182 µW.

3.5.5 Red LED 3 mm.

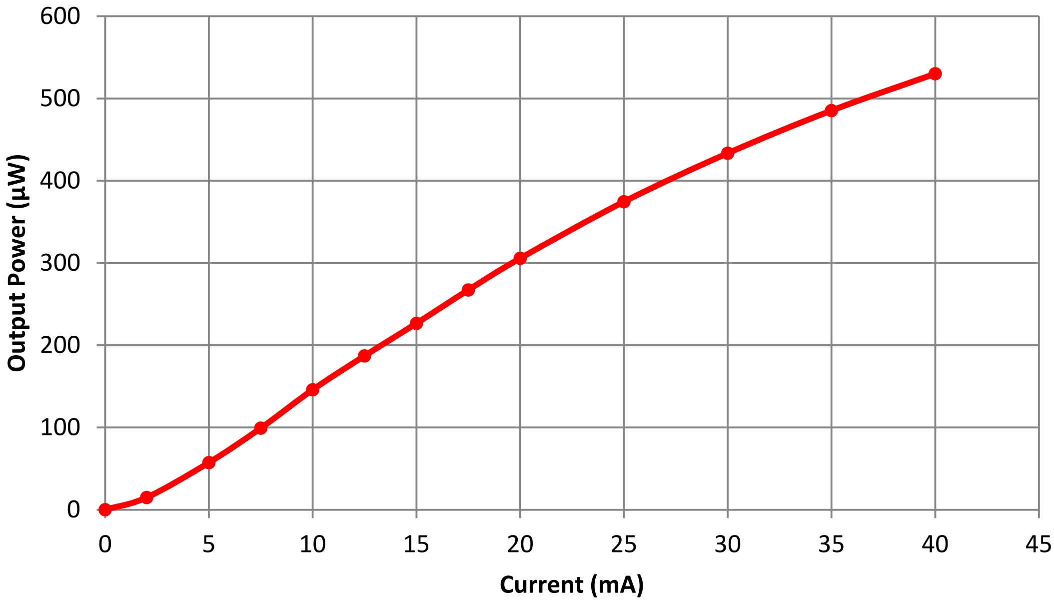


Fig.44: Red LED 3 mm - Output Power vs. Current.

For the red LED 3 mm Output Power-Current characteristic, the saturation point corresponds to 40 mA and the maximum output power is 530 µW.

3.5.6 Red LED 5 mm.

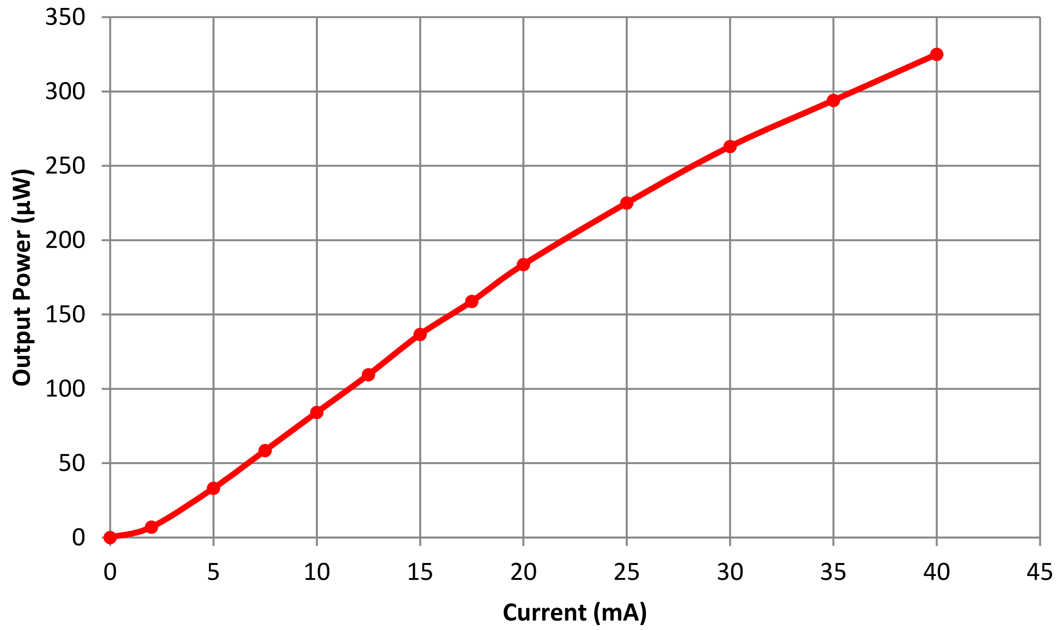


Fig.45: Red LED 5 mm - Output Power vs. Current.

For the red LED 5 mm, at 40 mA the saturation point is reached and the output power at this point is 325 µW.

3.5.7 White LED 3 mm.

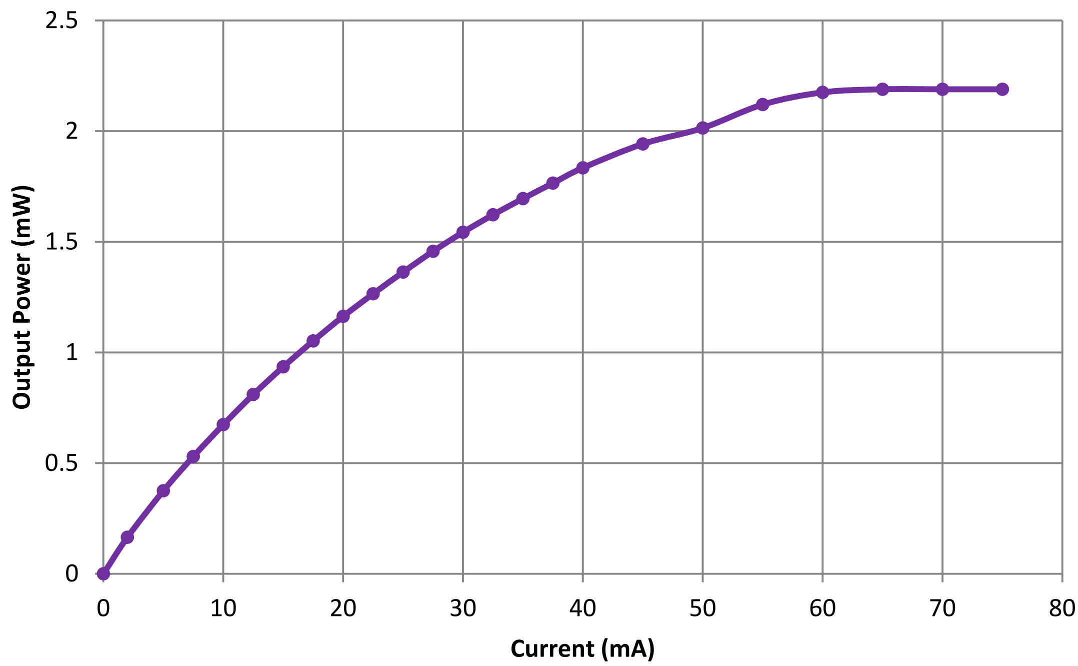


Fig.46: White LED 3 mm - Output Power vs. Current.

For the white LED 3 mm, above 65 mA the light intensity remains constant (saturation point). The maximum output optical power is 2.25 mW.

3.5.8 White LED 5 mm.

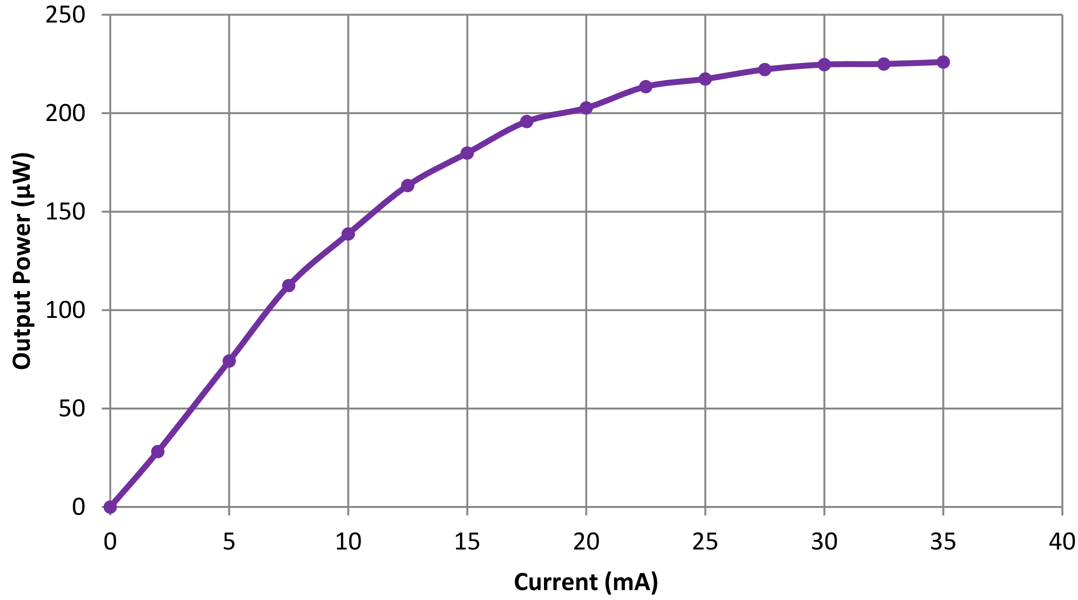


Fig.47: White LED 5 mm - Output Power vs. Current.

In the Output Power vs. Current characteristic of the white LED 5 mm, we can see that the saturation point is reached at 30 mA and the maximum output power is 226 µW.

3.6 Conclusions.

-The light vs. Current characteristics of several LEDs were measured and results are shown in the table below.

LED Colour	Diameter	Luminous intensity *(Typ)	Maximum output power
RED	3 mm	60 mcd	530 μw
RED	5 mm	80 mcd	325 μw
GREEN	3 mm	60 mcd	262 μw
GREEN	5 mm	60 mcd	182 μw
BLUE	3 mm	700 mcd	5.4 mW
BLUE	5 mm	60 mcd	500 μw
WHITE	3 mm	1200 mcd	2.25 mW
WHITE	5 mm	200 mcd	226 μw

*Data from the LEDs Datasheets (See Appendix)

1) The commercial LEDs tested have sublinear Light Power vs. Current characteristics, as expected.

2) The higher the luminous intensity of the LED, the higher the output power generated, which is quite straight forward.

4. Pulse Response.

4.1 Introduction

[9] The bandwidth of a LED corresponds to the frequency at which the power transmitted through the diode is reduced to half of its low-frequency value. It is also called the 3 dB frequency because the power transmitted at this frequency is reduced by 3 dB compared with its low frequency value.

When we apply a pulse to a LED, we can determine its bandwidth by measuring the rise time and the fall time of the pulse. The rise and fall times are defined as the time difference between the 10% and 90% points of the voltage (see Fig. below).

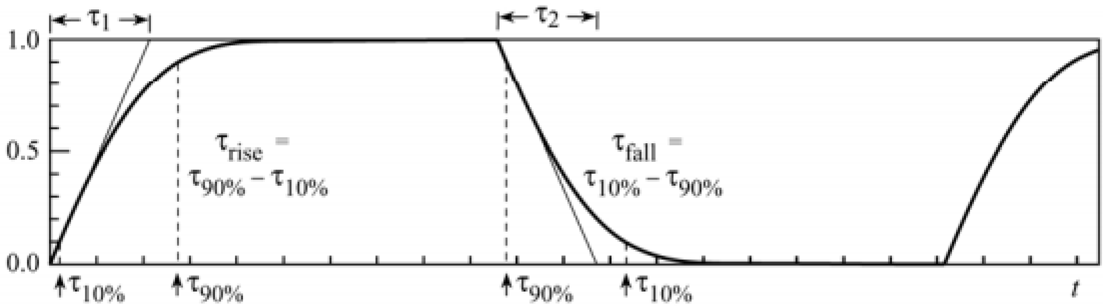


Fig.48: Rise and fall time of a pulse signal.

Assume that the time at which the amplitude decreases to 90% and 10% of its maximum value are $t_{90\%}$ and $t_{10\%}$ respectively:

$$e^{-t_{90\%}/\tau} = 90\% \text{ and } e^{-t_{10\%}/\tau} = 10\%$$

$$\tau_{fall} = \frac{t_{90\%}}{\tau_2} - \frac{t_{10\%}}{\tau_2} = -\ln 0.1 + \ln 0.9 = \ln 9 \ \text{ or } \tau_{fall} = t_{90\%} - t_{10\%} = \tau_2 \ln 9$$

The same consideration is valid for the rise time, so $\tau_{rise} = \tau_1 \ln 9$

When an LED is subjected to a pulse the output power increases according to:

$$P_{out}(t) = P_0 \left[1 - \exp\left(-\frac{t}{\tau}\right)\right]$$

And the power transfer function is given by

$$H_{LED}^2(w) = \frac{1}{1 + i\omega_{3dB}\tau}$$

The absolute value of the power transfer function is reduced to half at the 3dB frequency of the LED, so using:

$$H_{LED}^2(w) = \frac{1}{1 + i\omega_{3dB}\tau} = \frac{1}{2}$$

And

$$|H_{LED}(w)|^2 = \left|\frac{A}{A+iB}\right| = \frac{A}{\sqrt{A^2+B^2}} = \frac{1}{\sqrt{1+\omega_{3dB}^2\tau^2}}$$

We obtain

$$\frac{1}{2} = \frac{1}{\sqrt{1+\omega_{3dB}^2\tau^2}}$$

Solving for ω_{3dB}

$$\omega_{3dB} = \frac{\sqrt{3}}{\tau} \xrightarrow[w=2\pi f]{} f_{3dB} = \frac{\sqrt{3}}{2\pi\tau}$$

Consider a LED with a rise time τ_{rise} and a fall time τ_{fall}. The 3 dB frequency of an LED is given by:

$$\Delta f = f_{3dB} = \frac{\sqrt{3}}{2\pi\tau} = \frac{\sqrt{3}}{2\pi\tau_{rise}} = \frac{\sqrt{3}\ln 9}{\pi(\tau_{rise}+\tau_{fall})} \cong \frac{1.2}{(\tau_{rise}+\tau_{fall})}$$

Note that this equation is just an approximation; since the rise and fall time are usually not exponential the numerical factor 1.2 in the numerator can vary between 1 and 1.5.

4.2 Motivation.

The aim of this experiment is to measure the rise and fall times of some commercial LEDs when applying pulses to them and determine the bandwidth.

4.3 Equipment needed.

-LEDs.
-Pulse generator.
-Photodetector.
-Oscilloscope.

4.4 Setup.

The experimental setup for the measurement is described in the following. The LED is driven on with the pulse generator, with which we can select the output voltage, pulse width and the period. To achieve a bigger bandwidth the pulse width should be as small as possible (logical!). The optical power (light) of the LED is detected by the photodetector which converts the light into an electrical signal and we can see the signal in the oscilloscope. From the oscilloscope we can measure the rise and fall times of the pulses applied with the option measure-cursor-time. Due to the fact that we are measuring with the cursor of the oscilloscope the measurements are not very exact but we can obtain an approximate measurement of the bandwidth.

The photodetector used in the experiment (Thorlabs Inc. Model 201-579-7227) has a response time <1 ns and therefore it can detect signals of GHz. Thus, the photodetector is much faster than the LED and it will not limit the speed of the output light of the LED. Also, the bandwidth of the oscilloscope used in the laboratory was 60 MHz.

Conditions of measurement:

We measured the bandwidth of the LEDs under the following conditions: the output voltage of the pulse applied was 3 V, the width was 50 μs and the period 2.5 ms.

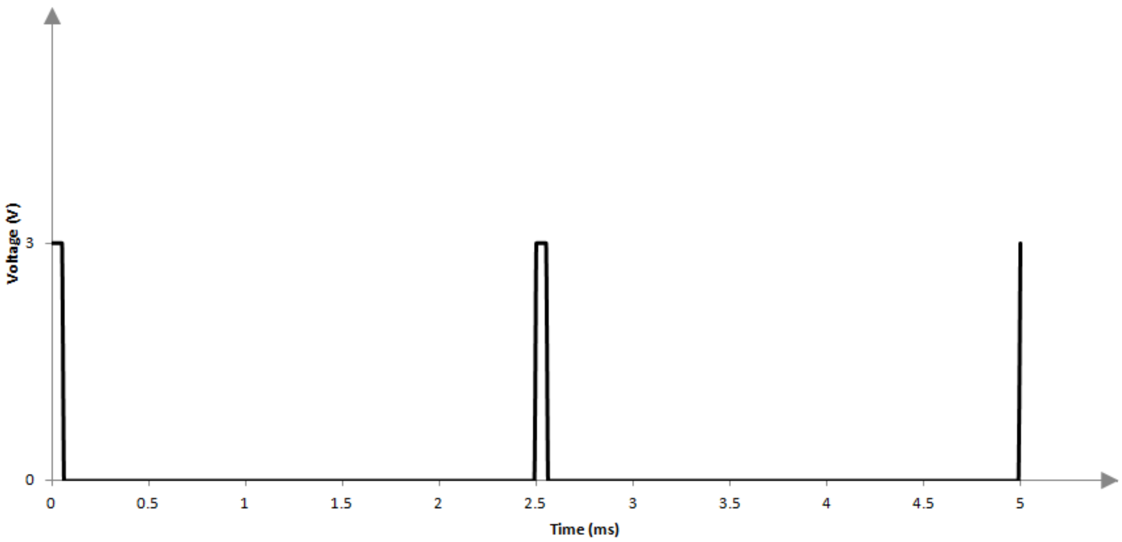


Fig.49: Pulse waveform applied to the LEDs.

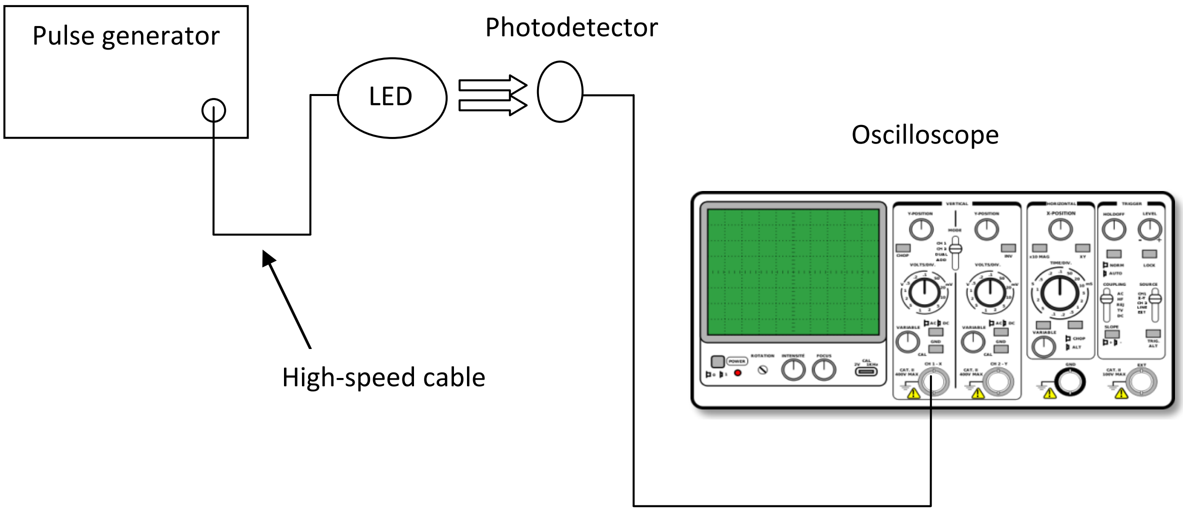
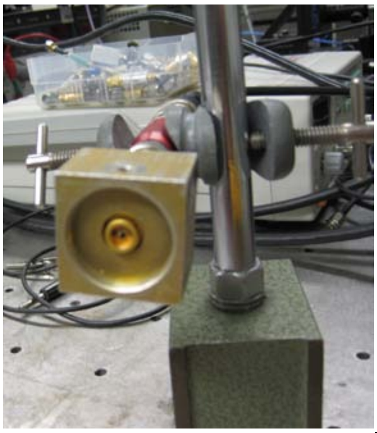
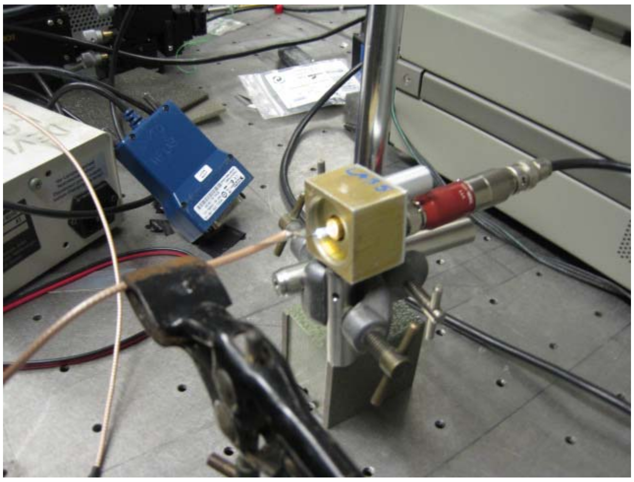


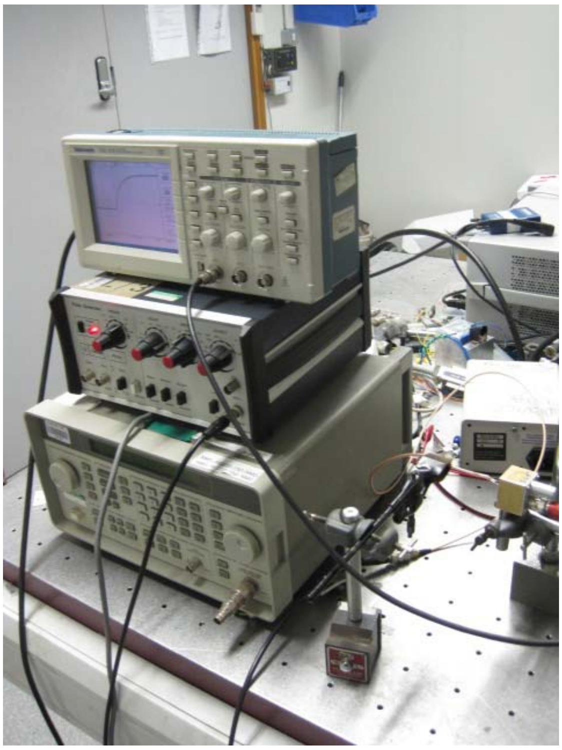
Fig.50: Schematic diagram of the setup for the pulse response experiment.



(a)



(b)



(c)

Fig.51: (a) Photodector used in the experiment. (b) LED and Photodetector. (c) General view of the setup for the experiment.

4.5 Results.

4.5.1 Blue LED 3 mm.

(a) (b)

Fig.52: (a) Blue LED 3 mm rise time. (b) Blue LED 3 mm fall time.

$$\tau_{\text{rise}} = \ 1\ \mu\text{s}$$
$$\tau_{\text{fall}} = 1.14\ \mu\text{s}$$

$$\Delta\text{f} = \cong \frac{1.2}{(\tau_{\text{rise}} + \tau_{\text{fall}})} = \frac{1.2}{1\ \mu\text{s} + 1.14\ \mu\text{s}} = 560.75\ \text{KHz}$$

4.5.2 Blue LED 5 mm.

In this case the signal detected on the oscilloscope was very weak and it was impossible to measure the rise and fall times properly even that we increased the width of the applied pulse to make LED brighter (see Fig.).

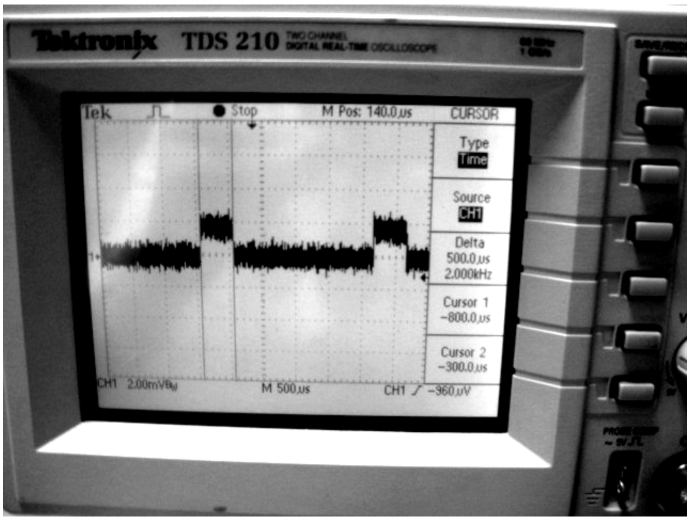
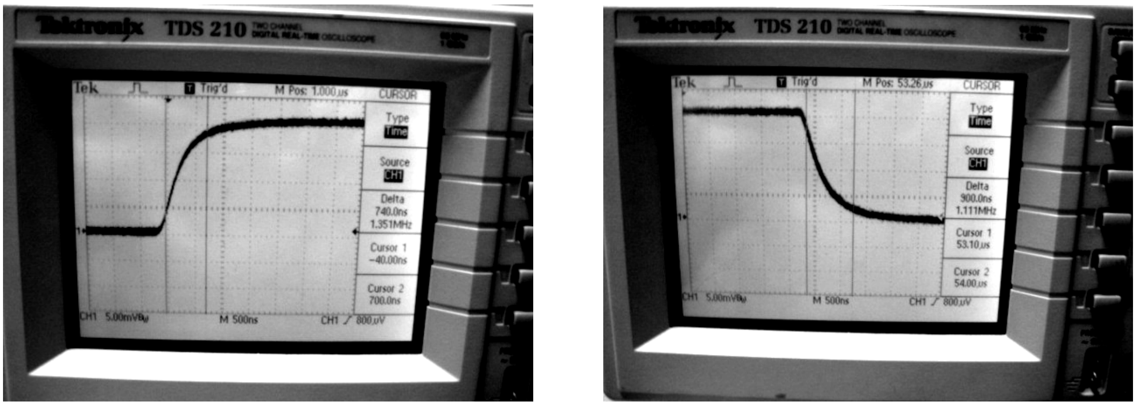


Fig.53: Blue LED 5 mm pulse response.

4.5.3 Green LED 3 mm.



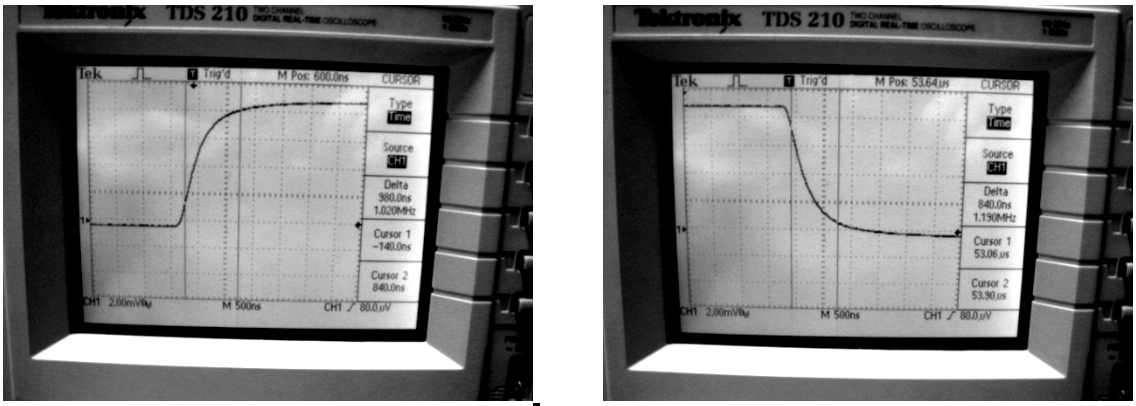
(a) (b)

Fig.54: (a) Green LED 3 mm rise time. (b) Green LED 3 mm fall time.

$\tau_{rise} = 740 \text{ ns}$
$\tau_{fall} = 900 \text{ ns}$

$$\Delta f =\cong \frac{1.2}{(\tau_{rise} + \tau_{fall})} = \frac{1.2}{740 \text{ ns} + 900 \text{ ns}} = 731.7 \text{ KHz}$$

4.5.4 Green LED 3 mm.



(a) (b)

Fig.55: (a) Green LED 5 mm rise time. (b) Green LED 5 mm fall time.

$\tau_{rise} = 980 \text{ ns}$
$\tau_{fall} = 840 \text{ ns}$

$$\Delta f =\cong \frac{1.2}{(\tau_{rise} + \tau_{fall})} = \frac{1.2}{980 \text{ ns} + 840 \text{ ns}} = 659.34 \text{ KHz}$$

4.5.5 Red LED 3 mm.

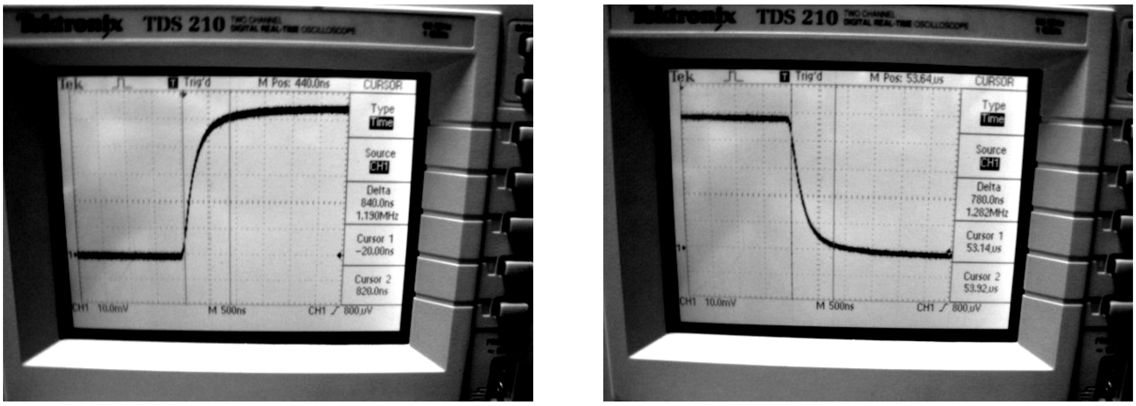
(a) (b)

Fig.56: (a) Red LED 3 mm rise time. (b) Red LED 3 mm fall time.

$\tau_{\text{rise}} = 700 \text{ ns}$
$\tau_{\text{fall}} = 680 \text{ ns}$

$$\Delta f = \cong \frac{1.2}{(\tau_{\text{rise}} + \tau_{\text{fall}})} = \frac{1.2}{700 \text{ ns} + 680 \text{ ns}} = 869.56 \text{ KHz}$$

4.5.6 Red LED 5 mm.



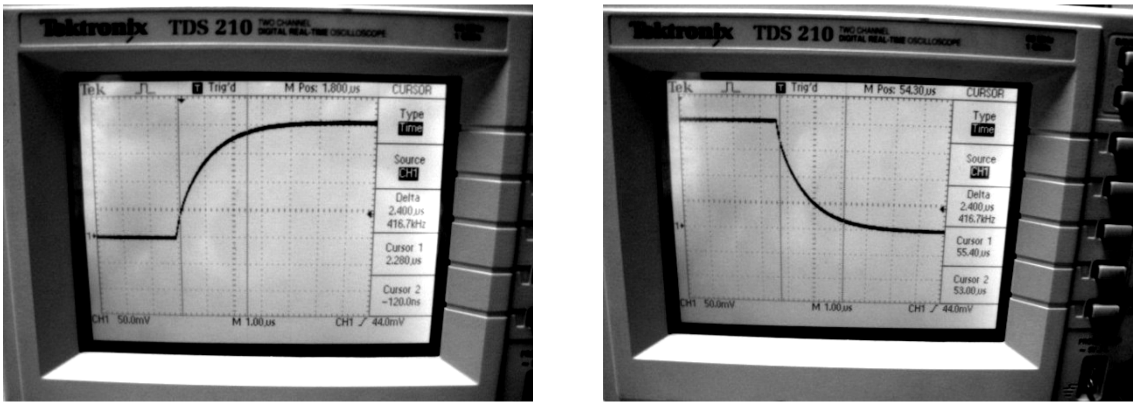
(a) (b)

Fig.57: (a) Red LED 5 mm rise time. (b) Red LED 5 mm fall time.

$\tau_{\text{rise}} = 840 \text{ ns}$
$\tau_{\text{fall}} = 780 \text{ ns}$

$$\Delta f = \cong \frac{1.2}{(\tau_{\text{rise}} + \tau_{\text{fall}})} = \frac{1.2}{840 \text{ ns} + 780 \text{ ns}} = 740.74 \text{ KHz}$$

4.5.7 White LED 3 mm.



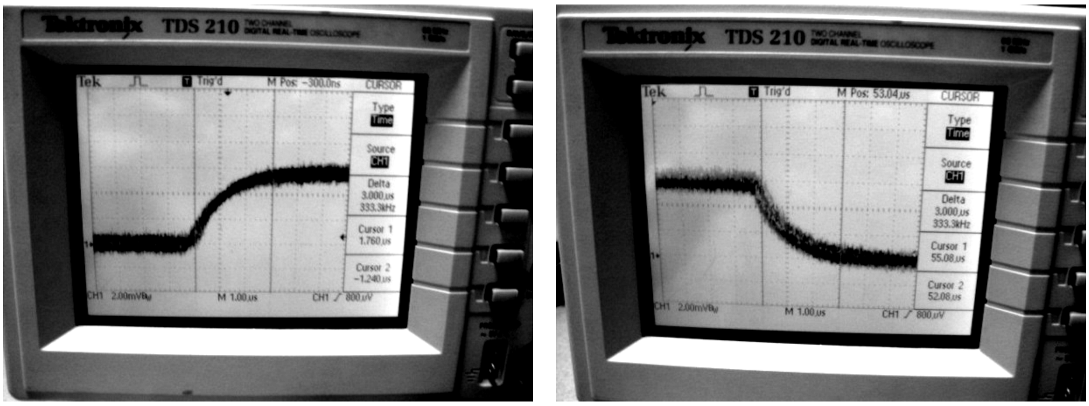
(a) (b)

Fig.58: (a) White LED 3 mm rise time. (b) White LED 3 mm fall time.

$\tau_{\text{rise}} = \ 2.4\ \mu\text{s}$
$\tau_{\text{fall}} = 2.4\ \mu\text{s}$

$$\Delta f = \cong \frac{1.2}{(\tau_{\text{rise}} + \tau_{\text{fall}})} = \frac{1.2}{2.4\ \mu\text{s} + 2.4\ \mu\text{s}} = 250\ \text{KHz}$$

4.5.8 White LED 5 mm.



(a) (b)

Fig.59: (a) White LED 5 mm rise time. (b) White LED 3 mm fall time.

$\tau_{\text{rise}} = \ 3\ \mu\text{s}$
$\tau_{\text{fall}} = 3\ \mu\text{s}$

$$\Delta f = \cong \frac{1.2}{(\tau_{\text{rise}} + \tau_{\text{fall}})} = \frac{1.2}{3\ \mu\text{s} + 3\ \mu\text{s}} = 200\ \text{KHz}$$

4.6 Conclusions.

The table below shows the results obtained to make a comparison between them:

Colour	**Diameter**	**Rise Time**	**Fall Time**	**Bandwidth**
Blue	3 mm	1 µs	1.14 µs	560.75 KHz
Blue	5 mm	-	-	-
Green	3 mm	740 ns	900 ns	731.7 KHz
Green	5 mm	980 ns	840 ns	659.34 KHz
Red	3 mm	700 ns	680 ns	869.56 KHz
Red	5 mm	840 ns	780 ns	740.74 KHz
White	3 mm	2.4 µs	2.4 µs	250 KHz
White	5 mm	3 µs	3 µs	200 z

1) The fastest devices listed in descending order are: Red, Green, Blue and White. We can notice that the slowest device is the white LED; this is due to the fact that the phosphor limits the speed of the overall response. It could be interesting to filter the slow phosphor response to achieve a higher bandwidth.

2) The measured bandwidth of these commercial LEDs are of hundreds KHz of order.

3) In general the LEDs do not have the same rise and fall times and they are slightly different, except for the white device that are exactly the same.

4) By analyzing the results, we can appreciate that the smaller the diameter of the LED, the bigger the bandwidth.

5. Frequency response.

5.1 Introduction.

The frequency response is one of the most important parameters to be considered in LEDs for optical communication systems. The graph below shows a typical frequency response of an LED:

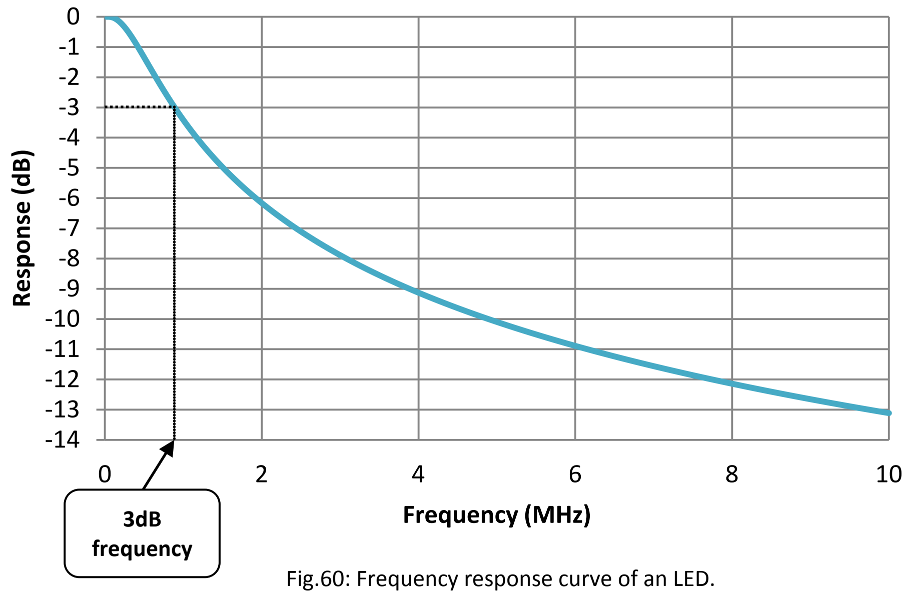


Fig.60: Frequency response curve of an LED.

From the graph, we can calculate the 3 dB frequency or bandwidth at the point that the response is reduced by 3 dB compared with the low frequency value. In the example above, the bandwidth of the LED is about 1 MHz.

5.2 Motivation.

The purpose of this experiment is to determine the bandwidth of different commercial LEDs.

5.3 Equipment needed.

-LEDs.
-Photodetector.
-Bias Tee.
-DC power supply.
-S-parameter analyzer.

5.3 Setup.

The emitted light of the LED is modulated and driven by a radiofrequency signal and a direct current via a bias tee. At the photodetector, the light is received and converted into a electrical signal and in the S-parameter analyzer we can see the frequency response of the LED for different applied currents.

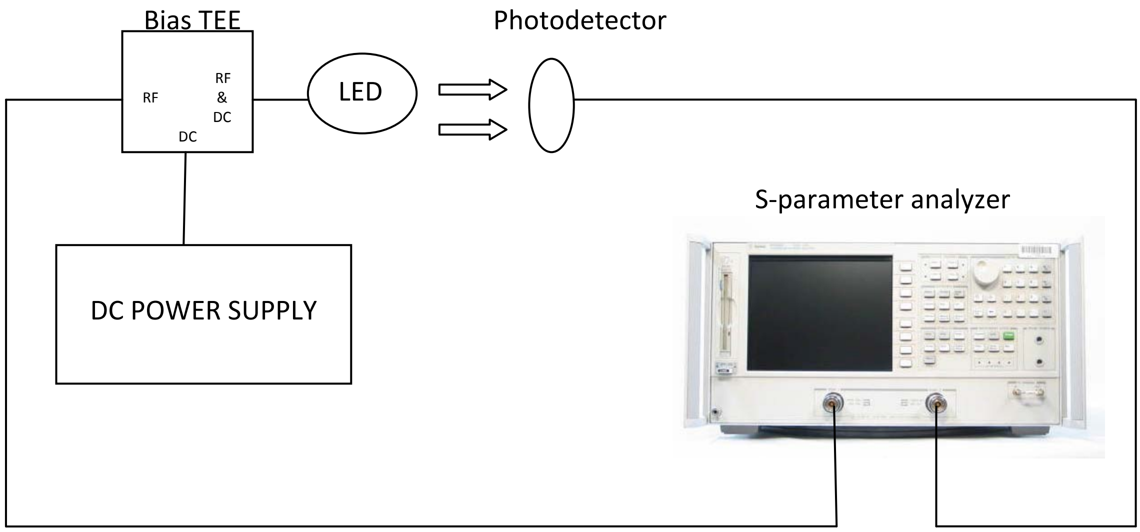


Fig.61: Block diagram of the setup for the frequency response of LEDs.

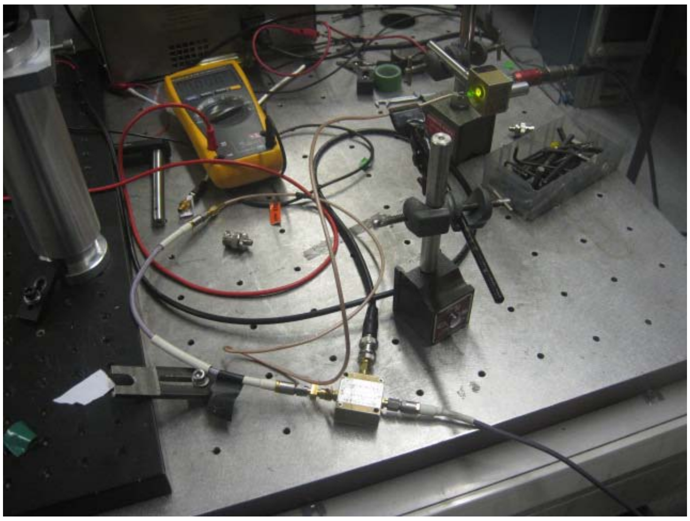


Fig.62: Photography of a part of the setup for the frequency response experiment.

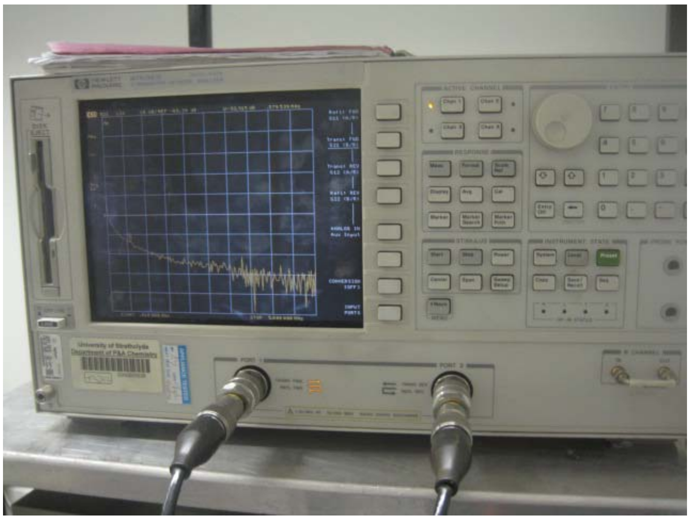


Fig.63: S-parameter analyzer used during the experiment.

5.4 Results.

Unfortunately, the results we obtained were not as expected. The frequency response of the LEDs should increase with the applied current (i.e the bandwidth for a bias current of 20 mA should be bigger than for a bias current of 30 mA) but this did not happened. Also, the measured bandwidths were too low, only a few KHz. The experiment was repeated several times because there could be any error in the setup, but the results achieved were similar. In Fig.64 we can see an example of the measured frequency response of the red LED 5 mm:

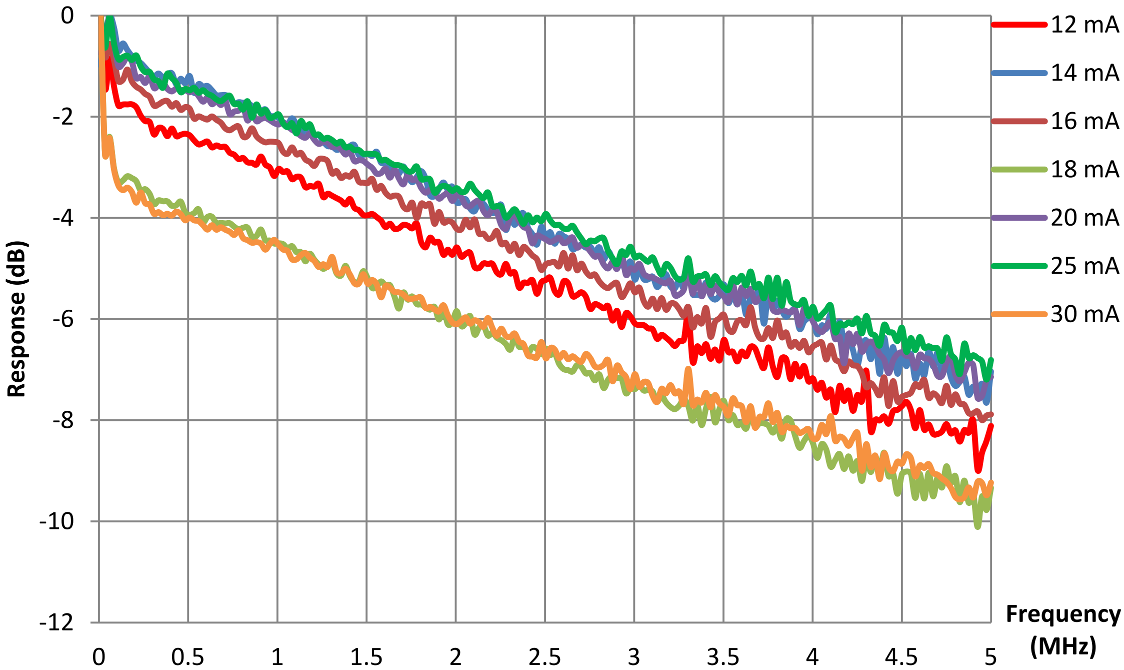


Fig.64: Measured frequency response of the red LED 5 mm.

We can notice that the bandwidth either increases or decreases as we increase the current, which does not make sense. All the devices presented the same problem. Probably, a reason for the unexpected measurements could be the heating of the devices.

5.4 Conclusions.

Although the results were not as expected, I still understood the purpose of the experiment and the subject matter. I investigated in depth possible problems and solutions but I did not achieve the desired results. Sometimes you learn more from errors than for getting the right results!.

6. LEDs Efficiency.

6.1 Introduction.

In this section, the LEDs power efficiencies are calculated. With the measured I-V and Light Power-Current characteristics, we can determine the power efficiency of the LEDs using the formula:

$$n_{power} = \frac{P}{I \cdot V} \times 100$$

6.2 Results.

In order to get a better comparison of the results obtained, we need to consider the same operation conditions for all the devices. For instance, we can calculate the power efficiency when all devices are operated at 20 mA.

6.2.1 Blue LED 3 mm.

For I_F=20 mA→ V=3.1 V, P=2.718 mW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{2.718 \text{ mW}}{20 \text{ mA} \cdot 3.1 \text{ V}} \times 100 = 4.38\%$$

6.2.2 Blue LED 5 mm.

For I_F=20 mA→ V=4.1 V, P=476.6 µW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{476.6 \ \mu\text{W}}{20 \text{ mA} \cdot 4{,}1 \text{ V}} \times 100 = 0.58\%$$

6.2.3 Green LED 3 mm

For I_F=20 mA→ V=2.1 V, P=86.78 µW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{86.78 \ \mu\text{W}}{20 \text{ mA} \cdot 2.1 \text{ V}} \times 100 = 0.20\%$$

6.2.4 Green LED 5 mm.

For I_F=20 mA→ V=1.95 V, P=44.79 µW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{44.79 \ \mu\text{W}}{20 \text{ mA} \cdot 1.95 \text{ V}} \times 100 = 0.11\%$$

6.2.5 Red LED 3 mm.

For I_F=20 mA→ V=1.75 V, P=305.6 µW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{305.6\ \mu W}{20\ mA \cdot 1.75\ V} \times 100 = 0.87\%$$

6.2.6 Red LED 5 mm.

For I_F=20 mA→ V=1.85 V, P=183.6 µW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{183.6\ \mu W}{20\ mA \cdot 1.85\ V} \times 100 = 0.49\%$$

6.2.7 White LED 3 mm.

For I_F=20 mA→ V=2.9 V, P=1.163 mW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{1.163\ mW}{20\ mA \cdot 2.9\ V} \times 100 = 2\%$$

6.2.8 White LED 5 mm.

For I_F=20 mA→ V=3.4 V, P=202.7 µW

$$n_{power} = \frac{P}{I \cdot V} \times 100 = \frac{202.7\ \mu W}{20\ mA \cdot 3{,}4\ V} \times 100 = 0.29\%$$

6.3 Conclusions.

The obtained results are shown in the table below:

LED COLOUR	DIAMETER	n_{power}
Blue	3 mm	4.38 %
Blue	5 mm	0.58 %
Green	3 mm	0.20 %
Green	5 mm	0.11 %
Red	3 mm	0.87 %
Red	5 mm	0.49%
White	3 mm	2 %
White	5 mm	0.29%

1) All these commercial LEDs have low power efficiencies.

2) The highest power efficient device is the blue LED 3 mm (4.38%) whereas the lowest power efficient device is the green LED 5 mm (0.11%).

ACKNOWLEDGMENTS

This paper was made possible by the support and assistance of a number of people whom I would like to personally thank. To my first supervisor, Dr. Anthony Kelly, for all his help, disposition for asking questions and friendliness; and to Scott Watson, PhD student who helped me in the laboratory work of the project.

Also, I would like to thank to all my family, friends and girlfriend for their support and encouragement in good and bad times.

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APPENDIX A. LEDs DATASHEETS

Order code	Manufacturer code	Description
55-1462	L-7104PBD-A	L-7104PBD-A LED 3MM BLUE DIFF 700MCD RC

Revision A
20/02/2007

Sales: 01206 751166
Sales@rapidelec.co.uk

Technical: 01206 835555
Tech@rapidelec.co.uk

Fax: 01206 751188
www.rapidonline.com

PRELIMINARY SPEC

Part Number: L-7104PBD-A Blue

ATTENTION
OBSERVE PRECAUTIONS
FOR HANDLING
ELECTROSTATIC
DISCHARGE
SENSITIVE
DEVICES

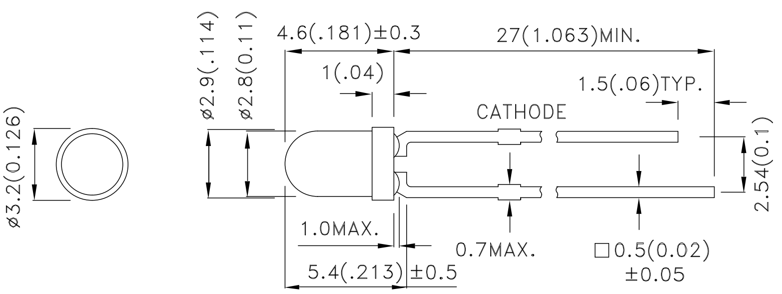
Features

- LOW POWER CONSUMPTION.
- POPULAR T-1 DIAMETER PACKAGE.
- GENERAL PURPOSE LEADS.
- RELIABLE AND RUGGED.
- LONG LIFE - SOLID STATE RELIABILITY.
- AVAILABLE ON TAPE AND REEL.
- RoHS COMPLIANT.

Description

The Blue source color devices are made with InGaN on SiC Light Emitting Diode.
Static electricity and surge damage the LEDS.
It is recommended to use a wrist band or anti-electrostatic glove when handling the LEDs.
All devices, equipment and machinery must be electrically grounded.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) [2] @ 20mA		Viewing Angle [1]
			Min.	Typ.	2θ1/2
L-7104PBD-A	Blue (InGaN)	BLUE DIFFUSED	180	700	30°

Notes:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.
2. Luminous intensity/ luminous Flux: +/-15%.

Electrical / Optical Characteristics at TA=25°C

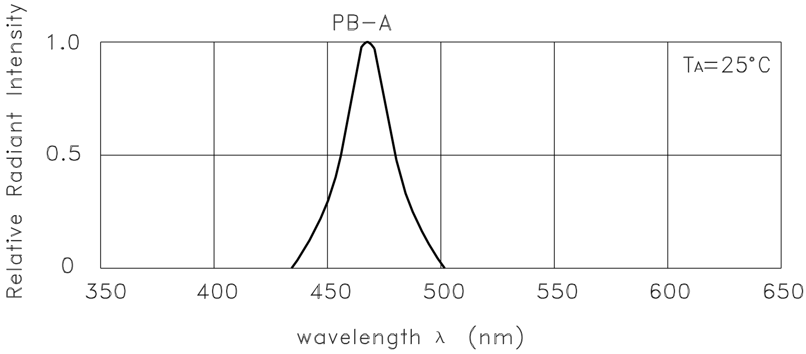
Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	Blue	468		nm	I_F=20mA
λD [1]	Dominant Wavelength	Blue	470		nm	I_F=20mA
Δλ1/2	Spectral Line Half-width	Blue	21		nm	I_F=20mA
C	Capacitance	Blue	100		pF	V_F=0V;f=1MHz
V_F [2]	Forward Voltage	Blue	3.2	4	V	I_F=20mA
I_R	Reverse Current	Blue		10	uA	V_R = 5V

Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at TA=25°C

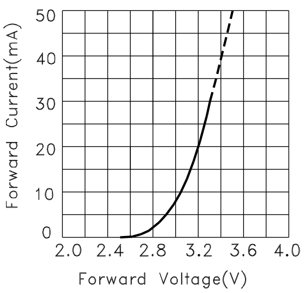
Parameter	Blue	Units
Power dissipation	120	mW
DC Forward Current	30	mA
Peak Forward Current [1]	100	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

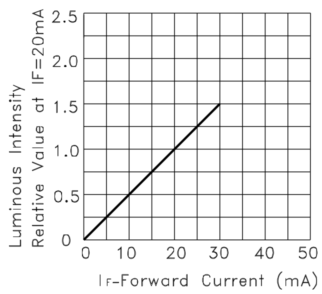


RELATIVE INTENSITY Vs. WAVELENGTH

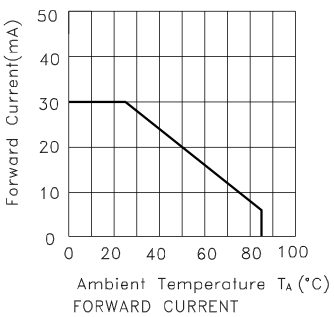
Blue **L-7104PBD-A**



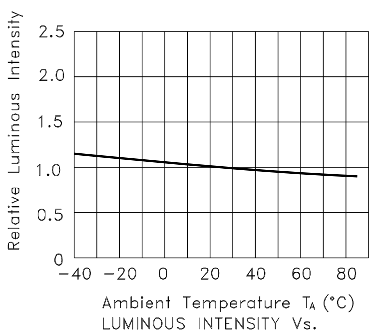
FORWARD CURRENT Vs.
FORWARD VOLTAGE



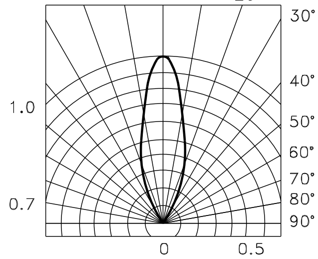
LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE



LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE



SPATIAL DISTRIBUTION

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LED MOUNTING METHOD

1. The lead pitch of the LED must match the pitch of the mounting holes on the PCB during component placement. Lead-forming may be required to insure the lead pitch matches the hole pitch. Refer to the figure below for proper lead forming procedures. (Fig. 1)

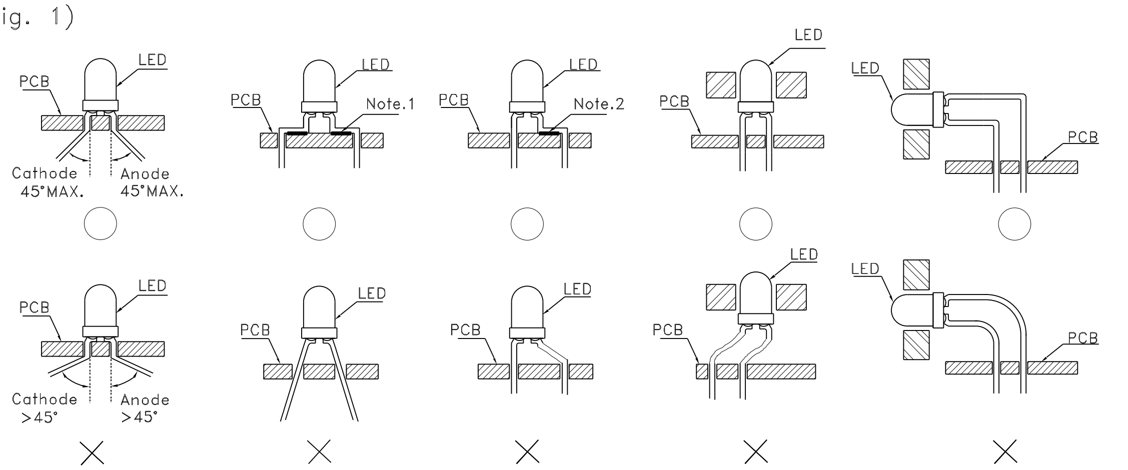


Fig.1

"○" Correct mounting method "×" Incorrect mounting method

Note 1-2 : Do not route PCB trace in the contact area between the leadframe and the PCB to prevent short-circuits.

2. When soldering wire to the LED, use individual heat-shrink tubing to insulate the exposed leads to prevent accidental contact short-circuit. (Fig. 2)

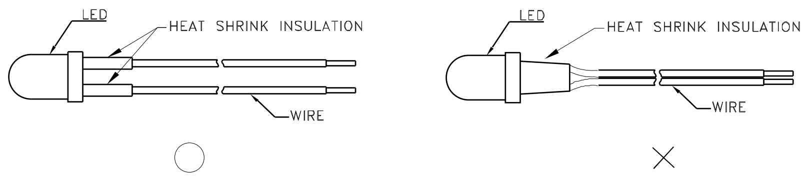


Fig. 2

3. Use stand-offs (Fig. 3) or spacers (Fig. 4) to securely position the LED above the PCB.

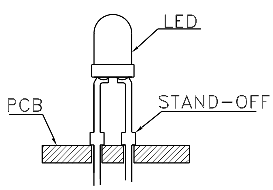


Fig. 3

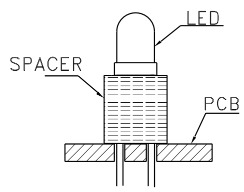


Fig. 4

LEAD FORMING PROCEDURES

1. Maintain a minimum of 2mm clearance between the base of the LED lens and the first lead bend. (Fig. 5 and 6)

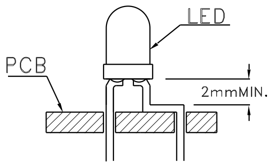


Fig. 5

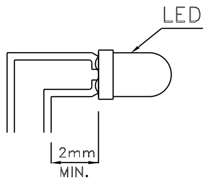


Fig. 6

2. Lead forming or bending must be performed before soldering, never during or after Soldering.
3. Do not stress the LED lens during lead-forming in order to fractures in the lens epoxy and damage the internal structures.
4. During lead forming, use tools or jigs to hold the leads securely so that the bending force will not be transmitted to the LED lens and its internal structures. Do not perform lead forming once the component has been mounted onto the PCB. (Fig. 7)
5. Do not bend the leads more than twice. (Fig. 8)

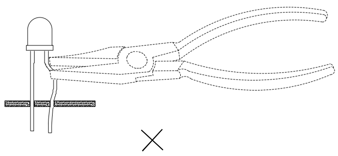


Fig. 7

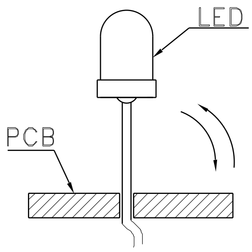


Fig. 8

6. After soldering or other high-temperature assembly, allow the LED to cool down to 50°C before applying outside force (Fig. 9). In general, avoid placing excess force on the LED to avoid damage. For any questions please consult with Kingbright representative for proper handling procedures.

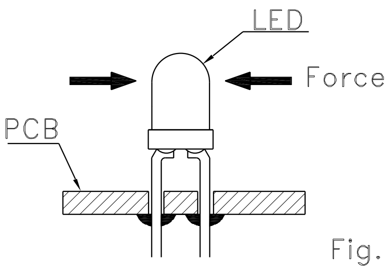


Fig. 9

5mm LEDs

Order code	Manufacturer code	Description
55-1480	L-7113MBD	5MM HI.INTENSITY DIFF.BLUE LED (RC)

Sales: 01206 751166
Sales@rapidelec.co.uk
Technical: 01206 835555
Tech@rapidelec.co.uk
Fax: 01206 751188
www.rapidelectronics.co.uk

ATTENTION
OBSERVE PRECAUTIONS
FOR HANDLING
ELECTROSTATIC
DISCHARGE
SENSITIVE
DEVICES

Part Number: L-7113MBD BLUE

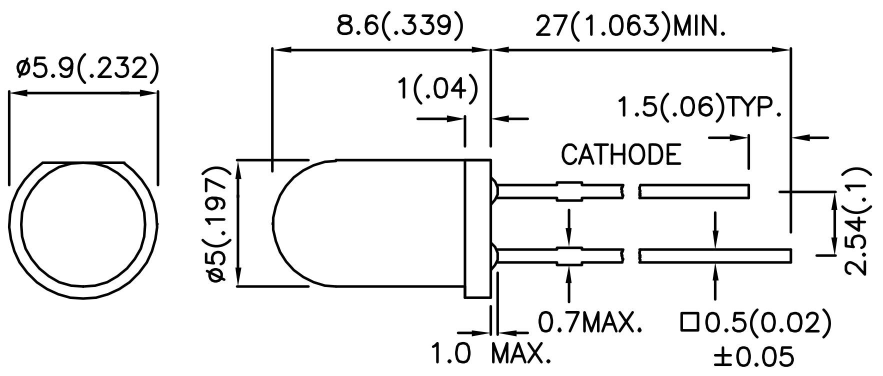
Features

- LOW POWER CONSUMPTION.
- POPULAR T-1 3/4 DIAMETER PACKAGE.
- GENERAL PURPOSE LEADS.
- RELIABLE AND RUGGED.
- LONG LIFE - SOLID STATE RELIABILITY.
- AVAILABLE ON TAPE AND REEL.
- RoHS COMPLIANT.

Description

The Blue source color devices are made with GaN on SiC Light Emitting Diode.
Static electricity and surge damage the LEDS.
It is recommended to use a wrist band or anti-electrostatic glove when handling the LEDs.
All devices, equipment and machinery must be electrically grounded.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

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Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) [2] @ 20 mA		Viewing Angle [1]
			Min.	Typ.	2θ1/2
L-7113MBD	BLUE (GaN)	BLUE DIFFUSED	36	60	20°

Notes:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.
2. Luminous intensity/ luminous Flux: +/-15%.

Electrical / Optical Characteristics at T_A=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	Blue	430		nm	I_F=20mA
λD [1]	Dominant Wavelength	Blue	466		nm	I_F=20mA
Δλ1/2	Spectral Line Half-width	Blue	60		nm	I_F=20mA
C	Capacitance	Blue	100		pF	V_F=0V;f=1MHz
V_F [2]	Forward Voltage	Blue	3.8	4.5	V	I_F=20mA
I_R	Reverse Current	Blue		10	uA	V_R = 5V

Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at T_A=25°C

Parameter	Blue	Units
Power dissipation	105	mW
DC Forward Current	30	mA
Peak Forward Current [1]	150	mA
Reverse Voltage	5	V
Operating / Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

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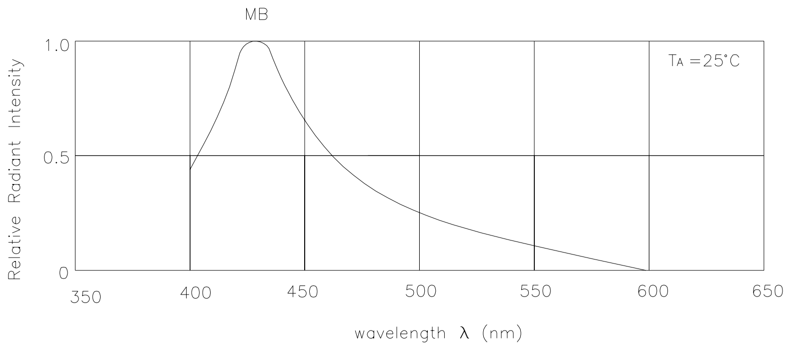
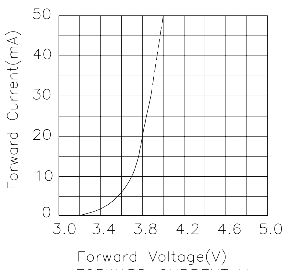
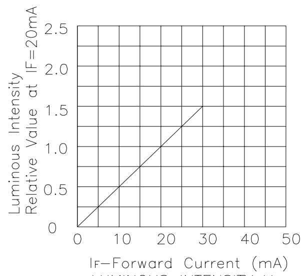


RELATIVE INTENSITY Vs. WAVELENGTH

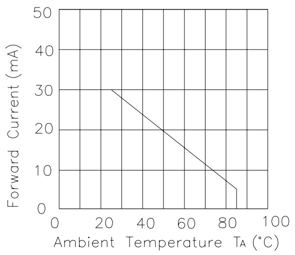
Blue **L-7113MBD**



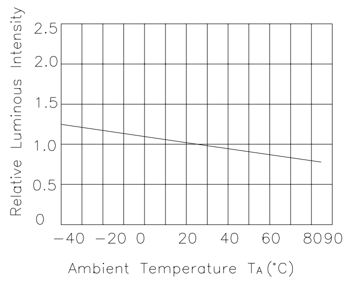
FORWARD CURRENT Vs.
FORWARD VOLTAGE



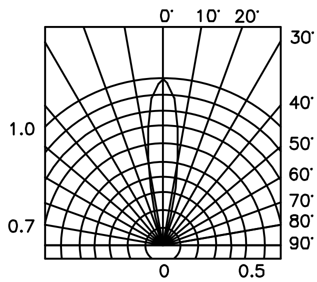
LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE



LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE



SPATIAL DISTRIBUTION

Kingbright

T-1 (3mm) SOLID STATE LAMP

Part Number: L-7104GT Green

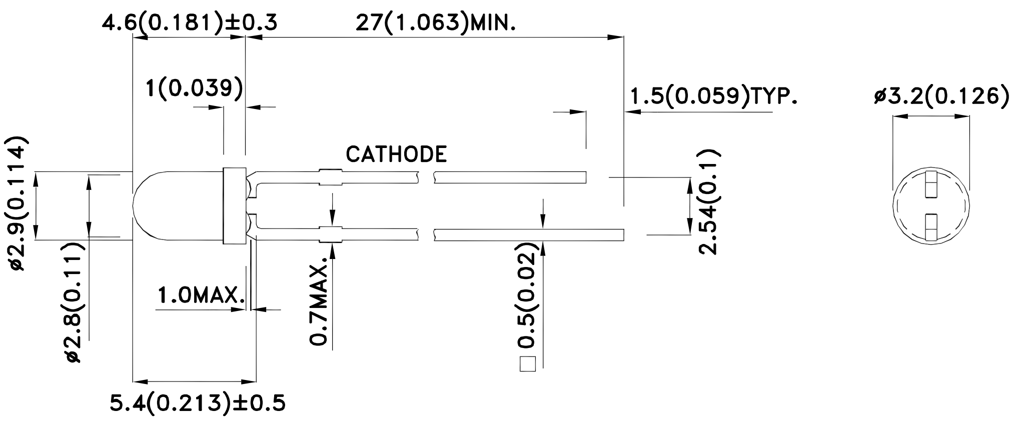
Features

- Low power consumption.
- Popular T-1 diameter package.
- General purpose leads.
- Reliable and rugged.
- Long life - solid state reliability.
- Available on tape and reel.
- RoHS compliant.

Description

The Green source color devices are made with Gallium Phosphide Green Light Emitting Diode.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. The specifications, characteristics and technical data described in the datasheet are subject to change without prior notice.

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) [2] @ 10mA		Viewing Angle [1]
			Min.	Typ.	2θ1/2
L-7104GT	Green (GaP)	Green Transparent	20	60	34°

Notes:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 of the optical peak value.
2. Luminous intensity/ luminous Flux: +/-15%.

Electrical / Optical Characteristics at TA=25°C

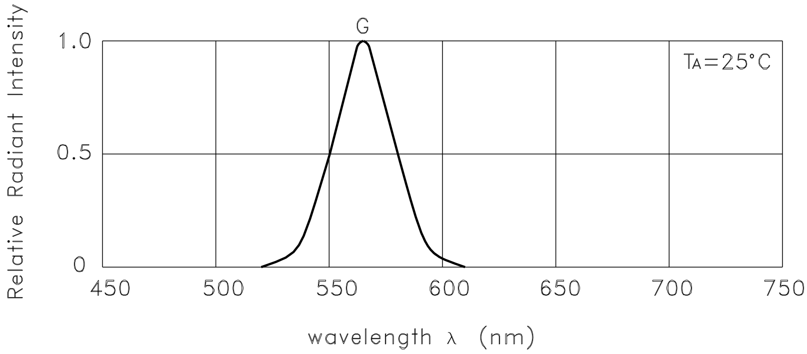
Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	Green	565		nm	I_F=20mA
λD [1]	Dominant Wavelength	Green	568		nm	I_F=20mA
Δλ1/2	Spectral Line Half-width	Green	30		nm	I_F=20mA
C	Capacitance	Green	15		pF	V_F=0V;f=1MHz
V_F [2]	Forward Voltage	Green	2.2	2.5	V	I_F=20mA
I_R	Reverse Current	Green		10	uA	V_R = 5V

Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at TA=25°C

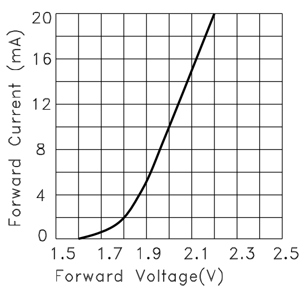
Parameter	Green	Units
Power dissipation	62.5	mW
DC Forward Current	25	mA
Peak Forward Current [1]	140	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

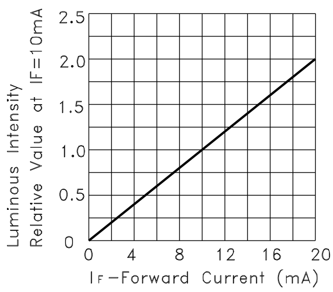


RELATIVE INTENSITY Vs. WAVELENGTH

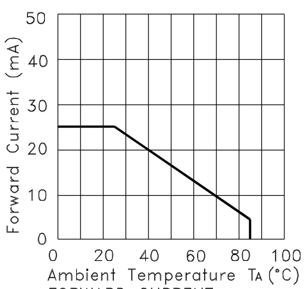
Green **L-7104GT**



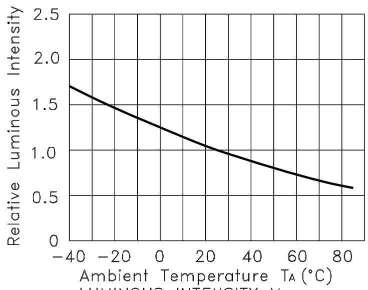
FORWARD CURRENT Vs.
FORWARD VOLTAGE



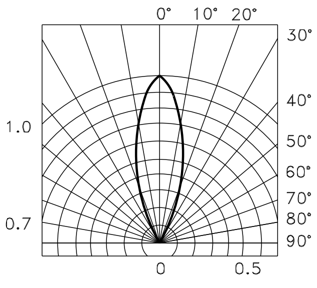
LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE

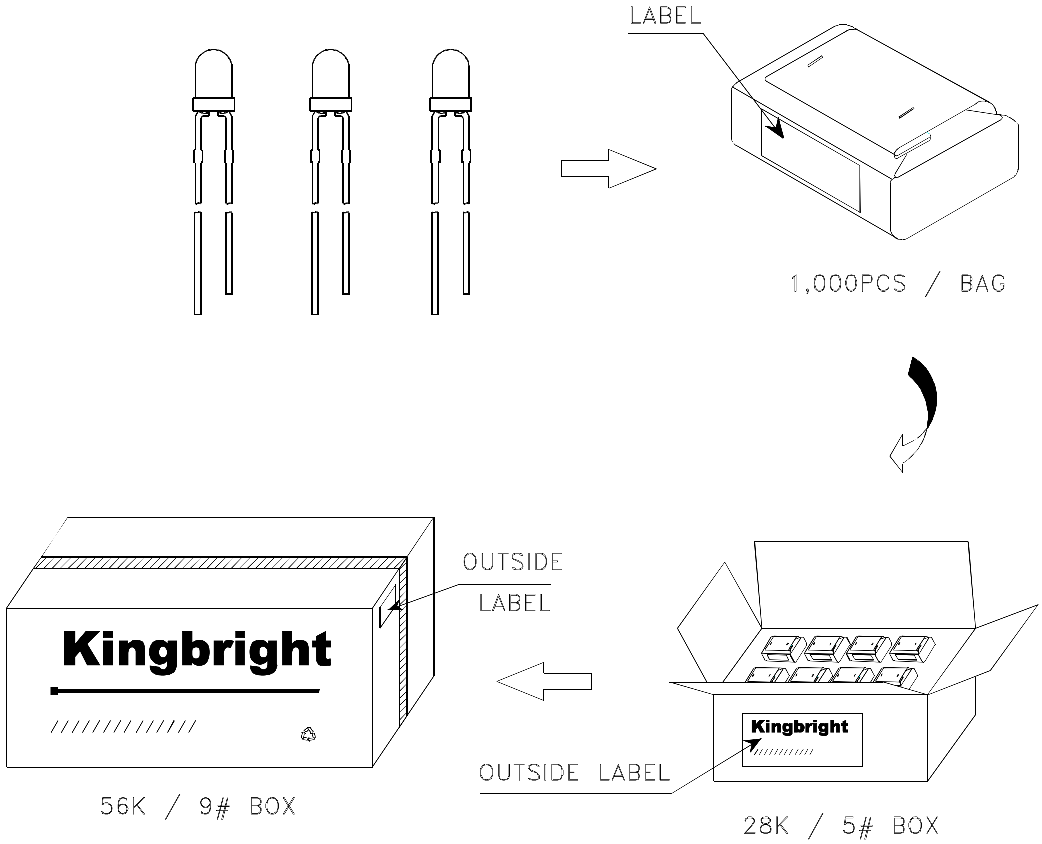


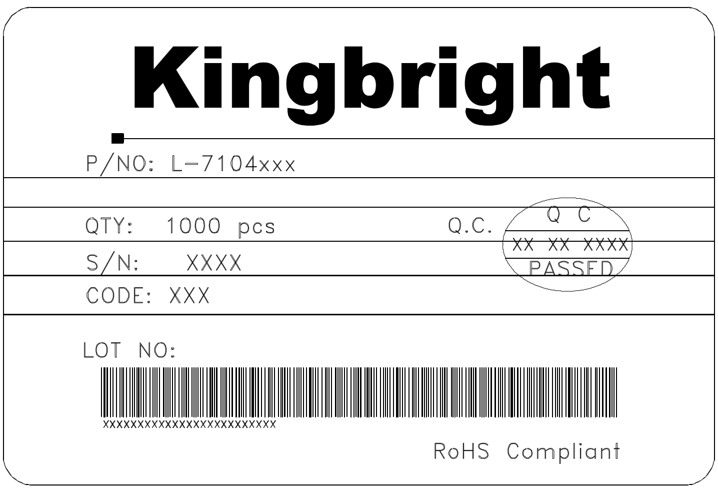
LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE



SPATIAL DISTRIBUTION

PACKING & LABEL SPECIFICATIONS **L-7104GT**





LED MOUNTING METHOD

1. The lead pitch of the LED must match the pitch of the mounting holes on the PCB during component placement. Lead–forming may be required to insure the lead pitch matches the hole pitch. Refer to the figure below for proper lead forming procedures.
(Fig. 1)

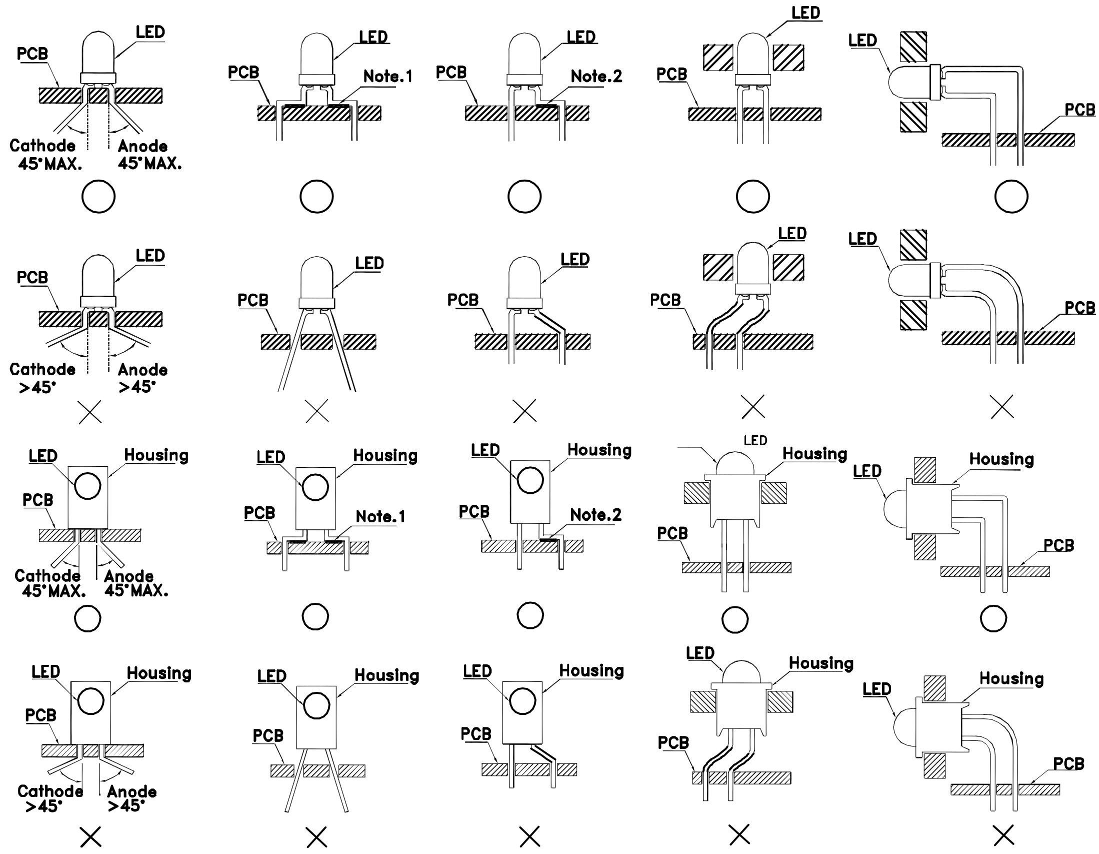


Fig.1

"○" Correct mounting method "×" Incorrect mounting method
Note 1–2 : Do not route PCB trace in the contact area between the leadframe and the PCB to prevent short–circuits.

2. When soldering wire to the LED, use individual heat–shrink tubing to insulate the exposed leads to prevent accidental contact short–circuit. (Fig. 2)
3. Use stand–offs (Fig. 3) or spacers (Fig. 4) to securely position the LED above the PCB.

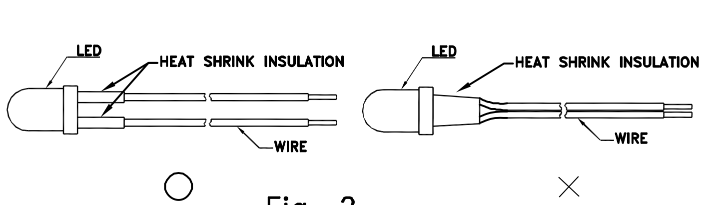


Fig. 2

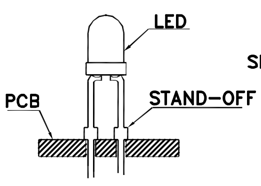


Fig. 3

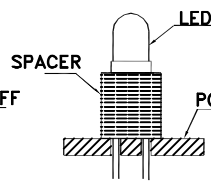


Fig. 4

LEAD FORMING PROCEDURES

1. Maintain a minimum of 2mm clearance between the base of the LED lens and the first lead bend. (Fig. 5 and 6)

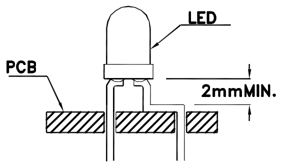


Fig. 5

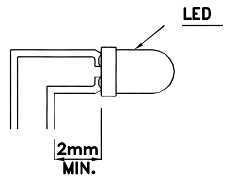


Fig. 6

2. Lead forming or bending must be performed before soldering, never during or after Soldering.
3. Do not stress the LED lens during lead–forming in order to fractures in the lens epoxy and damage the internal structures.
4. During lead forming, use tools or jigs to hold the leads securely so that the bending force will not be transmitted to the LED lens and its internal structures. Do not perform lead forming once the component has been mounted onto the PCB. (Fig. 7)
5. Do not bend the leads more than twice. (Fig. 8)
6. After soldering or other high–temperature assembly, allow the LED to cool down to 50°C before applying outside force (Fig. 9). In general, avoid placing excess force on the LED to avoid damage. For any questions please consult with Kingbright representative for proper handling procedures.

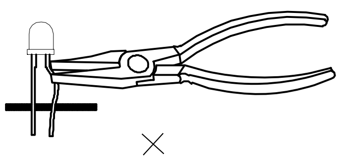


Fig. 7

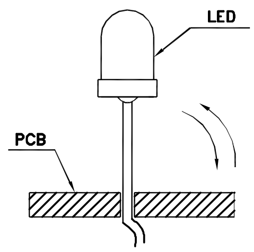


Fig. 8

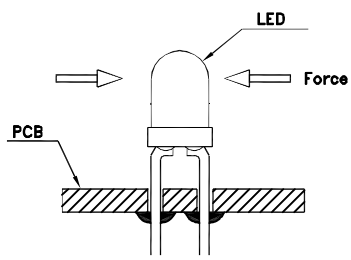
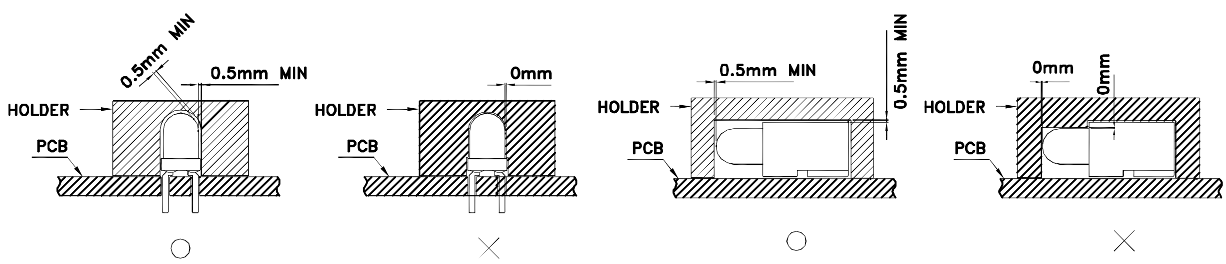


Fig. 9

7. No stress shall be applied on the LED during soldering to prevent damage.



Kingbright

T-1 3/4 (5mm) SOLID STATE LAMP

P/N: L-7113GT GREEN

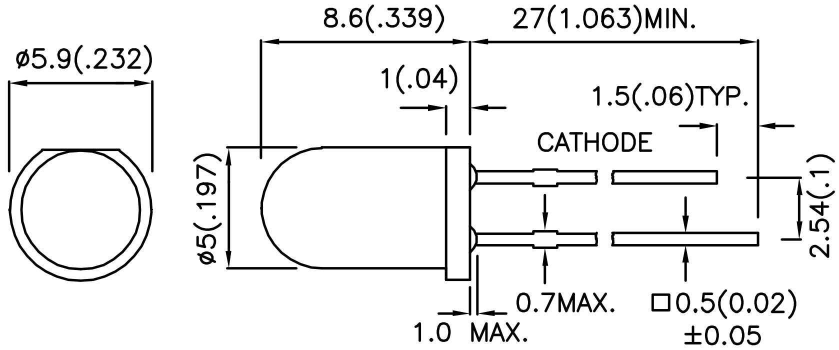
Features

- LOW POWER CONSUMPTION.
- POPULAR T-1 3/4 DIAMETER PACKAGE.
- GENERAL PURPOSE LEADS.
- RELIABLE AND RUGGED.
- LONG LIFE - SOLID STATE RELIABILITY.
- AVAILABLE ON TAPE AND REEL.
- RoHS COMPLIANT.

Description

The Green source color devices are made with Gallium Phosphide Green Light Emitting Diode.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) @ 10 mA		Viewing Angle
			Min.	Typ.	$2\theta 1/2$
L-7113GT	GREEN (GaP)	GREEN TRANSPARENT	18	60	20°

Note:
1. $\theta 1/2$ is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.

Electrical / Optical Characteristics at T_A=25°C

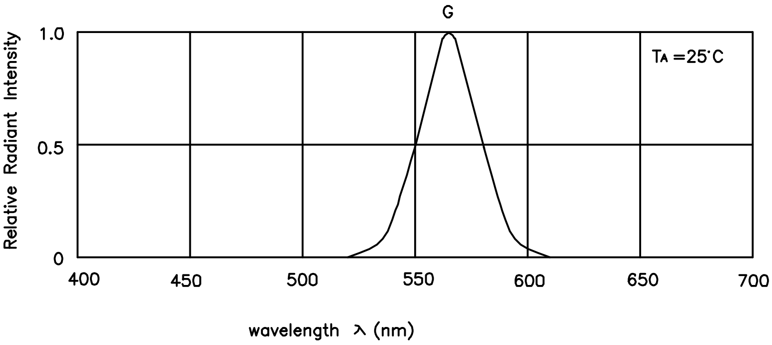
Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	Green	565		nm	I_F=20mA
λD	Dominant Wavelength	Green	568		nm	I_F=20mA
$\Delta\lambda 1/2$	Spectral Line Half-width	Green	30		nm	I_F=20mA
C	Capacitance	Green	15		pF	V_F=0V;f=1MHz
V_F	Forward Voltage	Green	2.2	2.5	V	I_F=20mA
I_R	Reverse Current	Green		10	uA	V_R = 5V

Absolute Maximum Ratings at T_A=25°C

Parameter	Green	Units
Power dissipation	105	mW
DC Forward Current	25	mA
Peak Forward Current [1]	140	mA
Reverse Voltage	5	V
Operating / Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

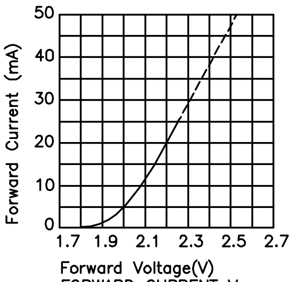
Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

Kingbright

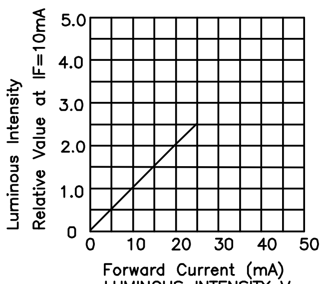


RELATIVE INTENSITY Vs. WAVELENGTH

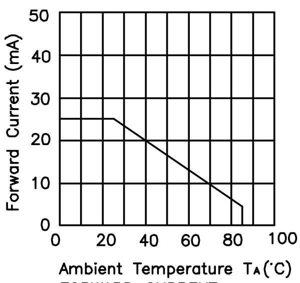
Green **L-7113GT**



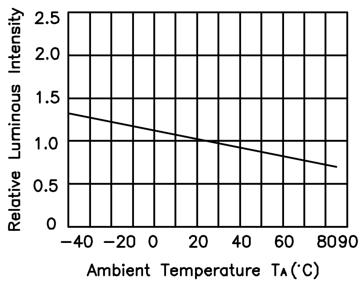
FORWARD CURRENT Vs.
FORWARD VOLTAGE



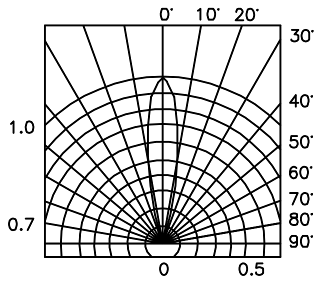
LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE



LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE



SPATIAL DISTRIBUTION

Remarks:
If special sorting is required (e.g. binning based on forward voltage, Luminous intensity/ luminous flux, or wavelength), the typical accuracy of the sorting process is as follows:
1. Wavelength: +/-1nm
2. Luminous intensity/ luminous flux: +/-15%
3. Forward Voltage: +/-0.1V
Note: Accuracy may depend on the sorting parameters.

Kingbright

T-1 (3mm) SOLID STATE LAMP

Part Number: L-7104IT High Efficiency Red

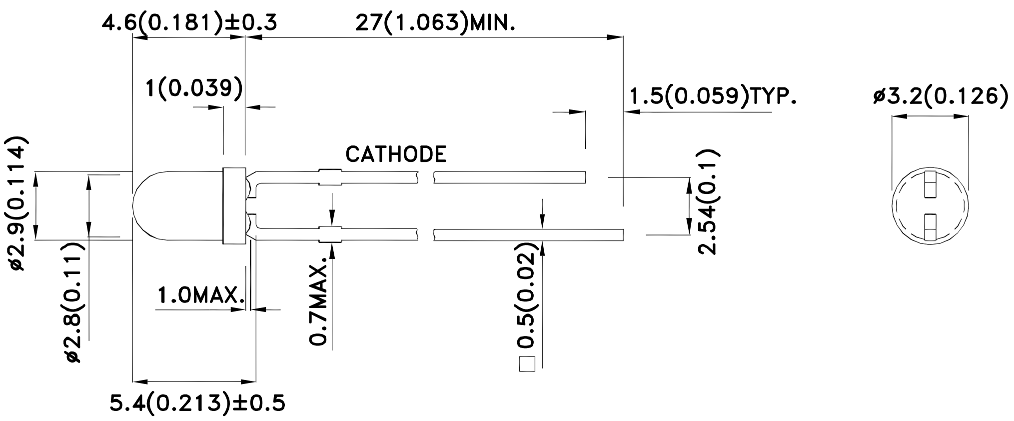
Features

- Low power consumption.
- Popular T-1 diameter package.
- General purpose leads.
- Reliable and rugged.
- Long life - solid state reliability.
- Available on tape and reel.
- RoHS compliant.

Description

The High Efficiency Red source color devices are made with Gallium Arsenide Phosphide on Gallium Phosphide Orange Light Emitting Diode.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. The specifications, characteristics and technical data described in the datasheet are subject to change without prior notice.

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) [2] @ 10mA		Viewing Angle [1]
			Min.	Typ.	2θ1/2
L-7104IT	High Efficiency Red (GaAsP/GaP)	Red Transparent	20	60	34°

Notes:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 of the optical peak value.
2. Luminous intensity/ luminous Flux: +/-15%.

Electrical / Optical Characteristics at TA=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	High Efficiency Red	627		nm	I_F=20mA
λD [1]	Dominant Wavelength	High Efficiency Red	625		nm	I_F=20mA
Δλ1/2	Spectral Line Half-width	High Efficiency Red	45		nm	I_F=20mA
C	Capacitance	High Efficiency Red	15		pF	V_F=0V;f=1MHz
V_F [2]	Forward Voltage	High Efficiency Red	2	2.5	V	I_F=20mA
I_R	Reverse Current	High Efficiency Red		10	uA	V_R = 5V

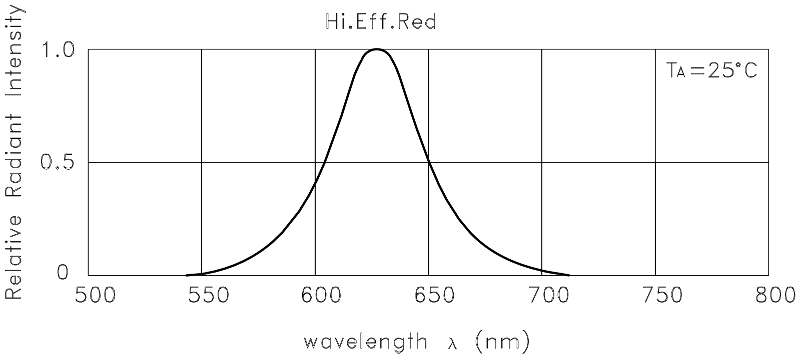
Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at TA=25°C

Parameter	High Efficiency Red	Units
Power dissipation	75	mW
DC Forward Current	30	mA
Peak Forward Current [1]	160	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

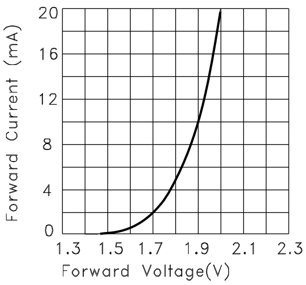
Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

Kingbright

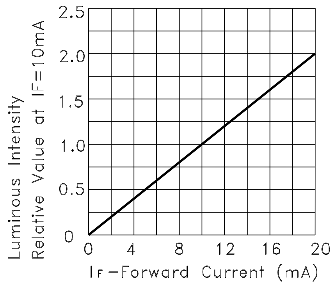


RELATIVE INTENSITY Vs. WAVELENGTH

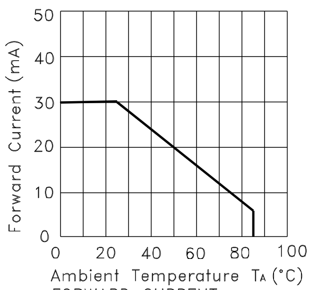
High Efficiency Red L-7104IT



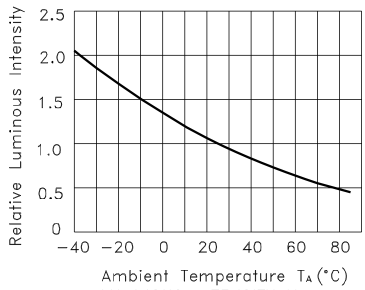
FORWARD CURRENT Vs.
FORWARD VOLTAGE



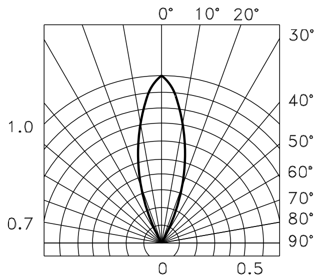
LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE



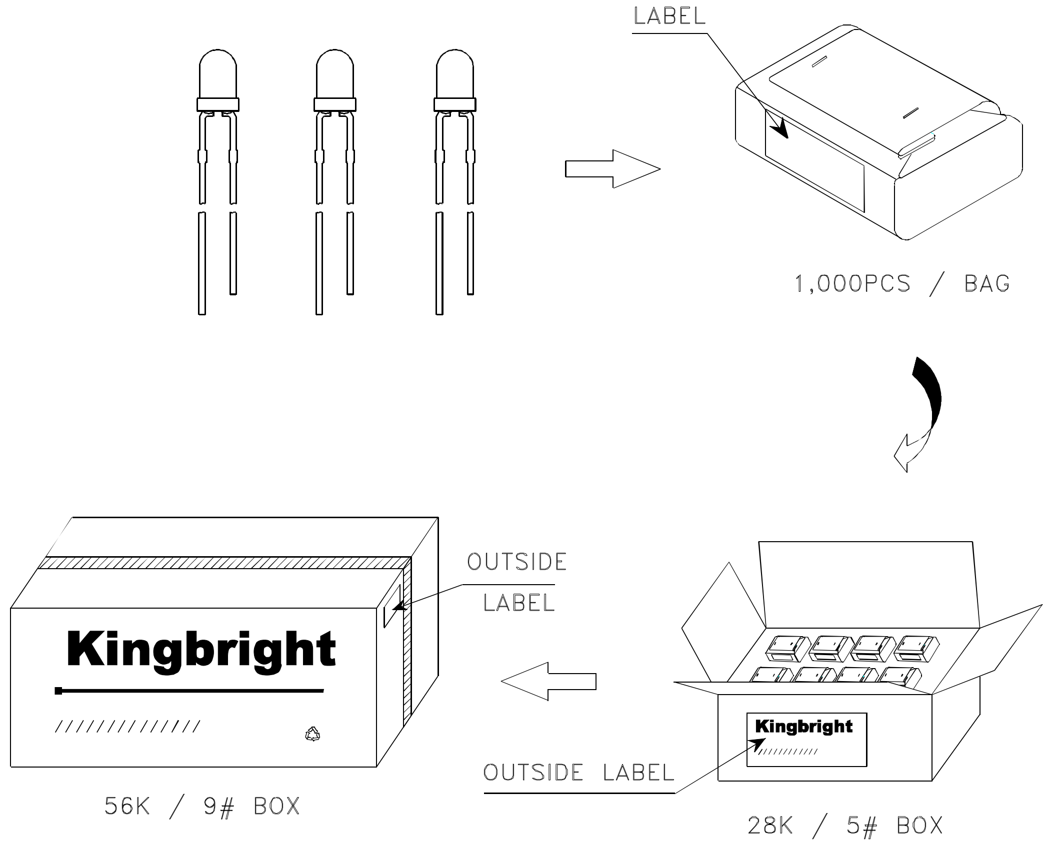
LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE

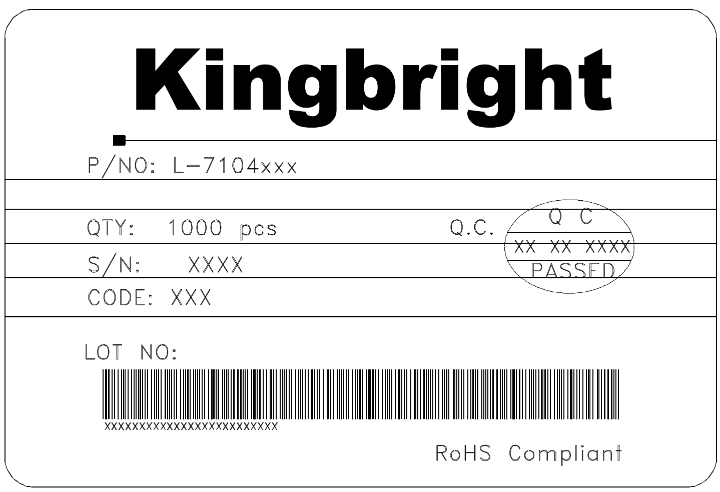


SPATIAL DISTRIBUTION

Kingbright

PACKING & LABEL SPECIFICATIONS **L-7104IT**





Kingbright

LED MOUNTING METHOD

1. The lead pitch of the LED must match the pitch of the mounting holes on the PCB during component placement. Lead-forming may be required to insure the lead pitch matches the hole pitch. Refer to the figure below for proper lead forming procedures.
(Fig. 1)

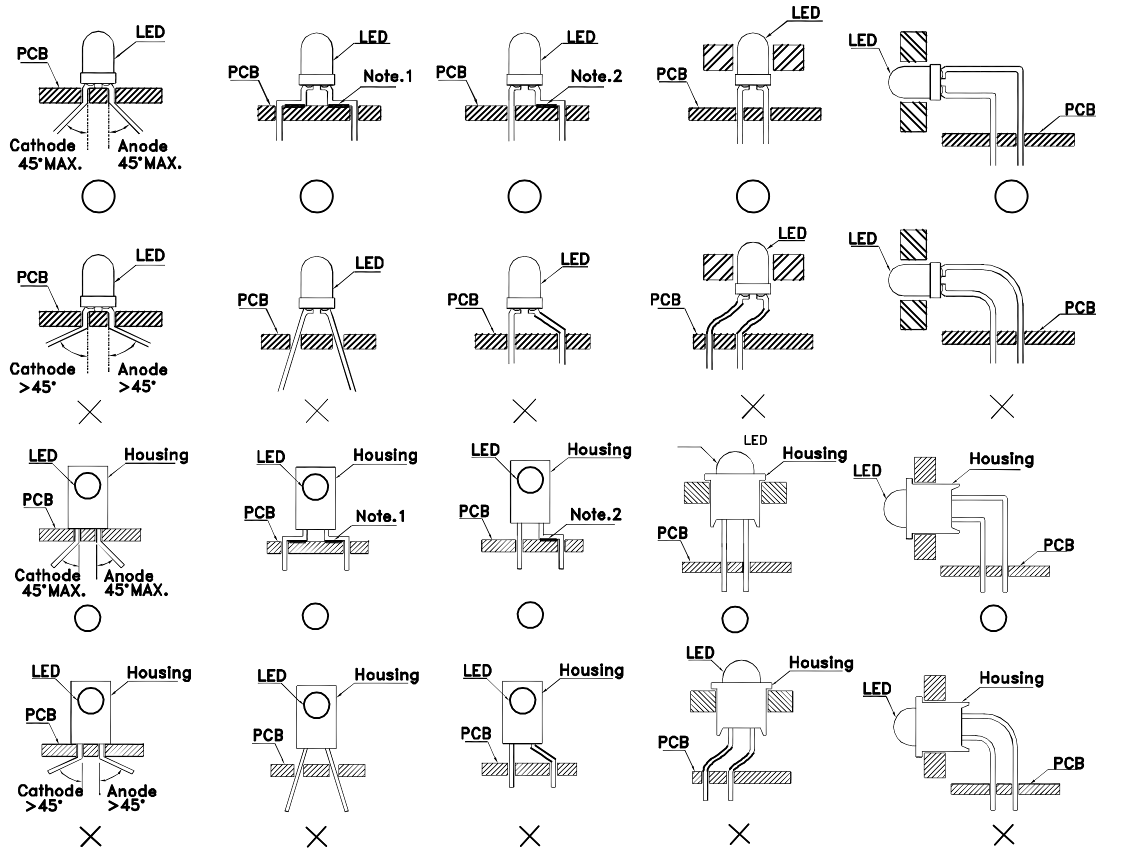


Fig.1

"○" Correct mounting method "×" Incorrect mounting method

Note 1-2 : Do not route PCB trace in the contact area between the leadframe and the PCB to prevent short-circuits.

2. When soldering wire to the LED, use individual heat-shrink tubing to insulate the exposed leads to prevent accidental contact short-circuit. (Fig. 2)
3. Use stand-offs (Fig. 3) or spacers (Fig. 4) to securely position the LED above the PCB.

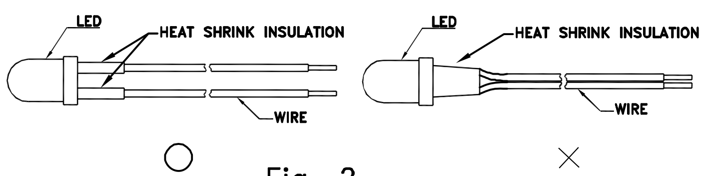


Fig. 2

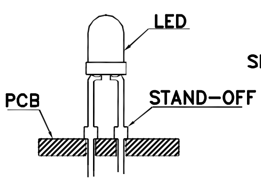


Fig. 3

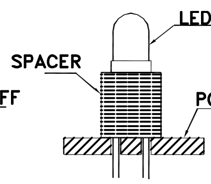


Fig. 4

LEAD FORMING PROCEDURES

1. Maintain a minimum of 2mm clearance between the base of the LED lens and the first lead bend. (Fig. 5 and 6)

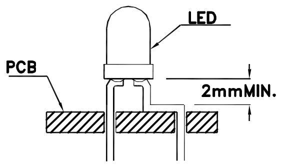


Fig. 5

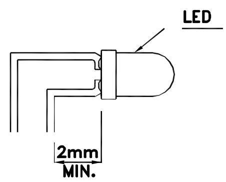


Fig. 6

2. Lead forming or bending must be performed before soldering, never during or after Soldering.
3. Do not stress the LED lens during lead–forming in order to fractures in the lens epoxy and damage the internal structures.
4. During lead forming, use tools or jigs to hold the leads securely so that the bending force will not be transmitted to the LED lens and its internal structures. Do not perform lead forming once the component has been mounted onto the PCB. (Fig. 7)
5. Do not bend the leads more than twice. (Fig. 8)
6. After soldering or other high–temperature assembly, allow the LED to cool down to 50°C before applying outside force (Fig. 9). In general, avoid placing excess force on the LED to avoid damage. For any questions please consult with Kingbright representative for proper handling procedures.

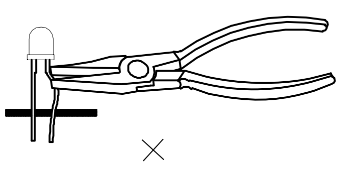


Fig. 7

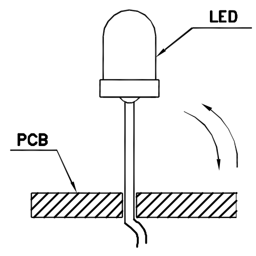


Fig. 8

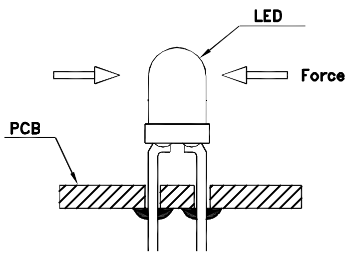
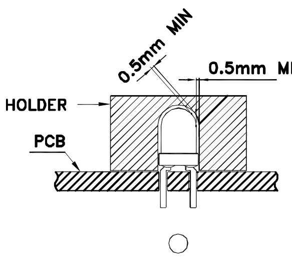
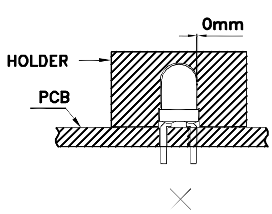
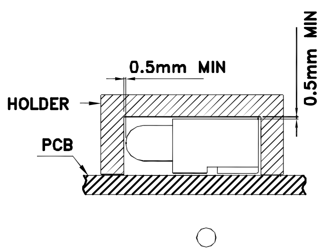


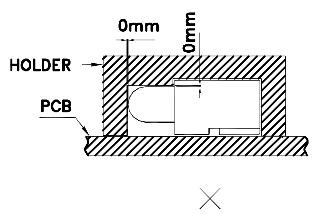
Fig. 9

7. No stress shall be applied on the LED during soldering to prevent damage.









L-7113IT HIGH EFFICIENCY RED

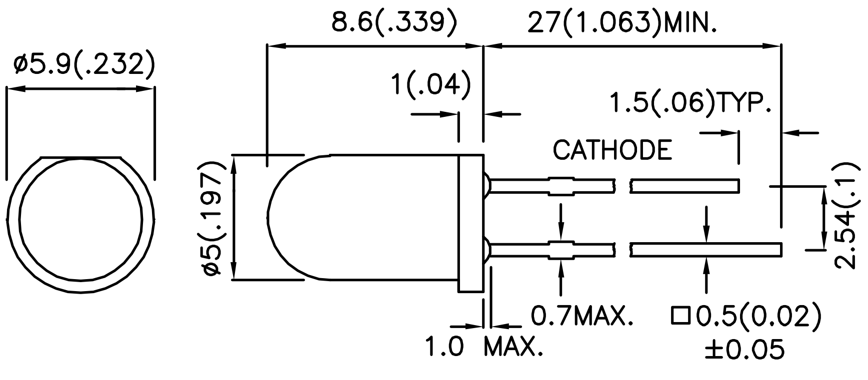
Features

- LOW POWER CONSUMPTION.
- POPULAR T-1 3/4 DIAMETER PACKAGE.
- GENERAL PURPOSE LEADS.
- RELIABLE AND RUGGED.
- LONG LIFE - SOLID STATE RELIABILITY.
- AVAILABLE ON TAPE AND REEL.
- RoHS COMPLIANT.

Description

The High Efficiency Red source color devices are made with Gallium Arsenide Phosphide on Gallium Phosphide Orange Light Emitting Diode.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) @ 10mA		Viewing Angle
			Min.	Typ.	2 θ 1/2
L-7113IT	HIGH EFFICIENCY RED (GaAsP/GaP)	RED TRANSPARENT	28	80	20°

Note:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.

Electrical / Optical Characteristics at T_A=25°C

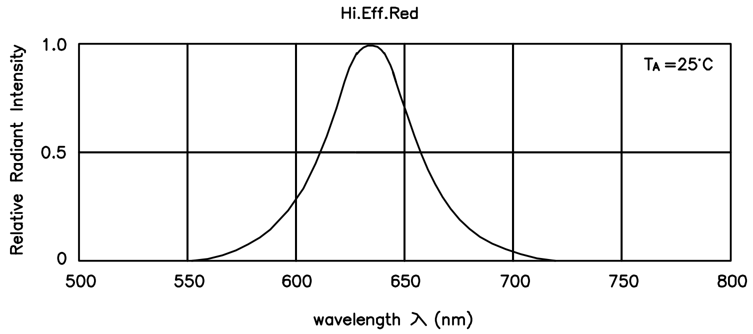
Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	High Efficiency Red	627		nm	I_F=20mA
λD	Dominant Wavelength	High Efficiency Red	625		nm	I_F=20mA
Δλ1/2	Spectral Line Half-width	High Efficiency Red	45		nm	I_F=20mA
C	Capacitance	High Efficiency Red	15		pF	V_F=0V;f=1MHz
V_F	Forward Voltage	High Efficiency Red	2.0	2.5	V	I_F=20mA
I_R	Reverse Current	High Efficiency Red		10	uA	V_R = 5V

Absolute Maximum Ratings at T_A=25°C

Parameter	High Efficiency Red	Units
Power dissipation	105	mW
DC Forward Current	30	mA
Peak Forward Current [1]	160	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

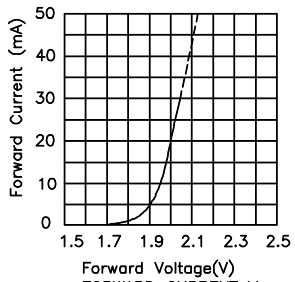
Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

Kingbright

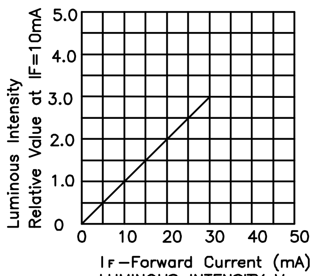


RELATIVE INTENSITY Vs. WAVELENGTH

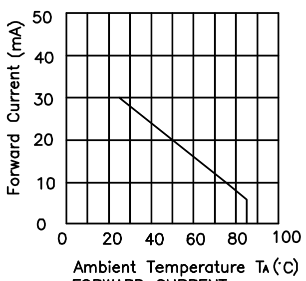
High Efficiency Red **L-7113IT**



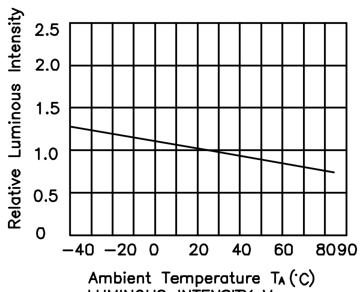
FORWARD CURRENT Vs.
FORWARD VOLTAGE



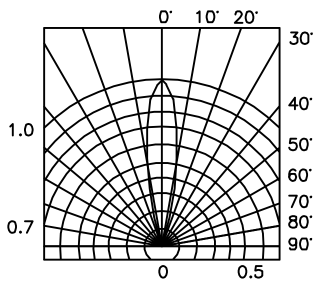
LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE



LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE



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Remarks:

If special sorting is required (e.g. binning based on forward voltage, luminous intensity, or wavelength), the typical accuracy of the sorting process is as follows:

1. Wavelength: +/-1nm
2. Luminous Intensity: +/-15%
3. Forward Voltage: +/-0.1V

Note: Accuracy may depend on the sorting parameters.

3mm LEDs

Order code	Manufacturer code	Description
55-1630	L-7104PWC	L-7104PWC-A 3MM WHITE LED (RC)

Sales: 01206 751166 **Sales@rapidelec.co.uk**

Technical: 01206 835555 **Tech@rapidelec.co.uk**

Fax: 01206 751188 **www.rapidonline.com**

PRELIMINARY SPEC

Part Number: L-7104PWC-A White

ATTENTION
OBSERVE PRECAUTIONS
FOR HANDLING
ELECTROSTATIC
DISCHARGE
SENSITIVE
DEVICES

Features

- LOW POWER CONSUMPTION.
- POPULAR T-1 DIAMETER PACKAGE.
- GENERAL PURPOSE LEADS.
- RELIABLE AND RUGGED.
- LONG LIFE - SOLID STATE RELIABILITY.
- AVAILABLE ON TAPE AND REEL.
- RoHS COMPLIANT.

Description

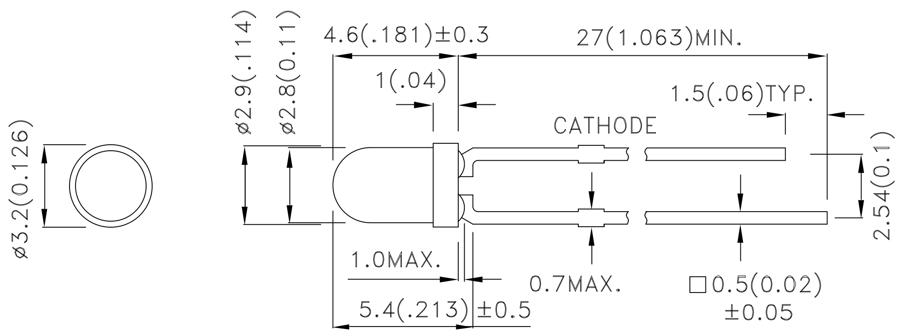
The source color devices are made with InGaN on SiC Light Emitting Diode.

Static electricity and surge damage the LEDS.

It is recommended to use a wrist band or anti-electrostatic glove when handling the LEDs.

All devices, equipment and machinery must be electrically grounded.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) [2] @ 20mA		Viewing Angle [1]
			Min.	Typ.	2θ1/2
L-7104PWC-A	White (InGaN)	WATER CLEAR	280	1200	34°

Notes:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.
2. Luminous intensity/ luminous Flux: +/-15%.

Electrical / Optical Characteristics at T_A=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
V_F [1]	Forward Voltage	White	3.2	4.0	V	I_F=20mA
I_R	Reverse Current	White		10	uA	V_R = 5V
X [2]	Chromaticity Coordinates	White	0.31			
Y [2]			0.31			
C	Capacitance	White	100		pF	V_F=0V;f=1MHz

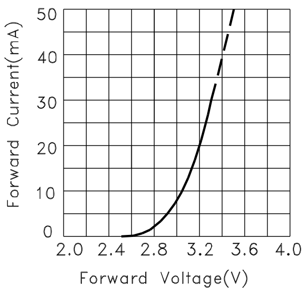
Notes:
1. Forward Voltage: +/-0.1V.
2. Measurement tolerance of the chromaticity coordinates is ±0.02.

Absolute Maximum Ratings at TA=25°C

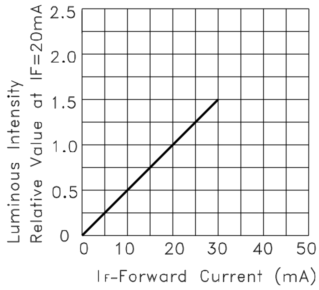
Parameter	White	Units
Power dissipation	120	mW
DC Forward Current	30	mA
Peak Forward Current [1]	100	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

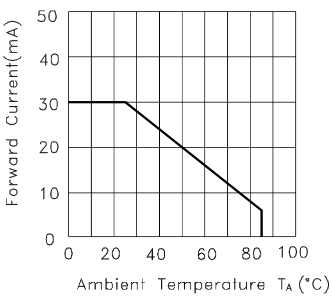
White **L-7104PWC-A**



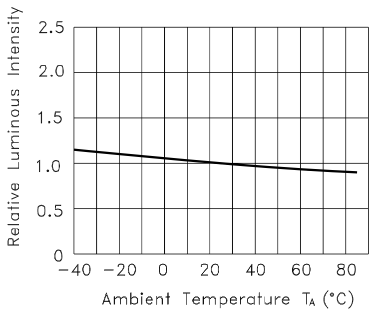
FORWARD CURRENT Vs.
FORWARD VOLTAGE



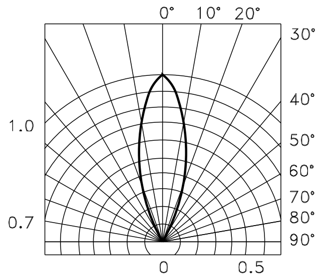
LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE



LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE



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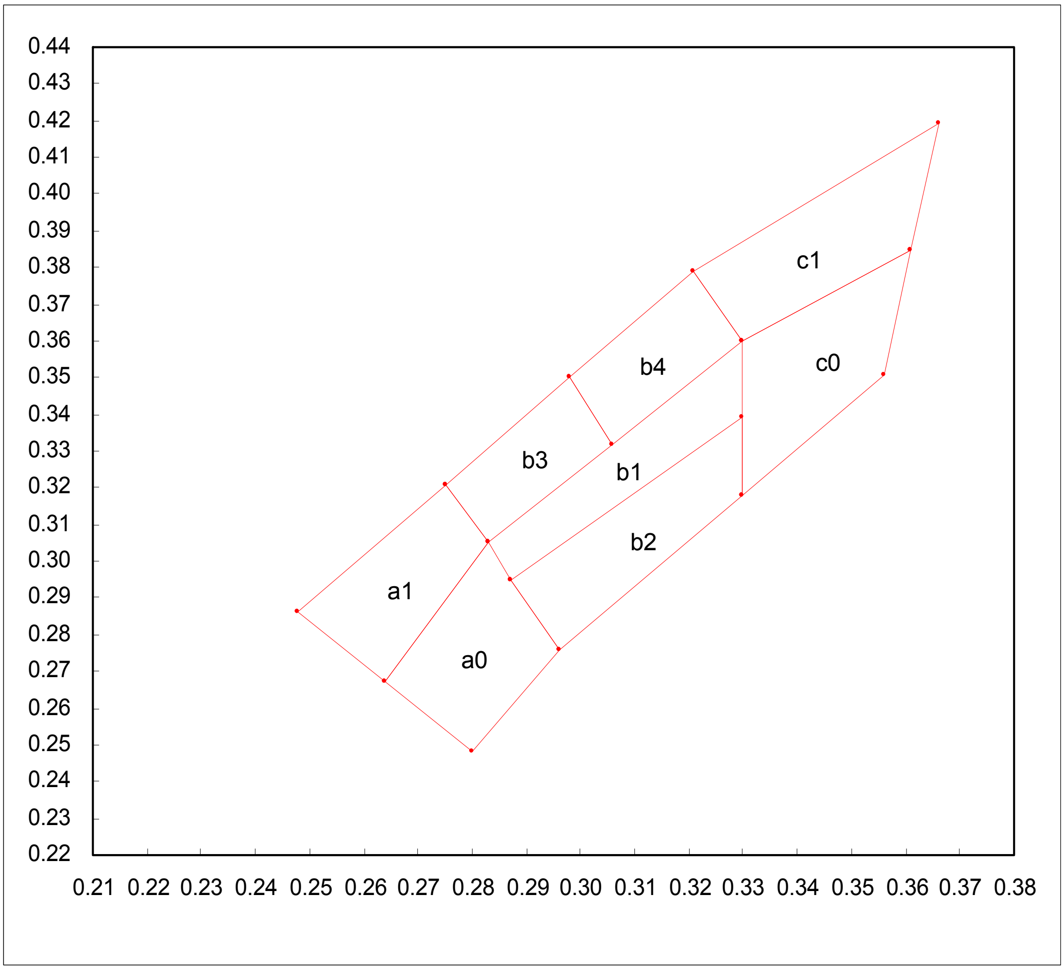
Kingbright

L-7104PWC-A

White CIE



a0				
X	0.264	0.283	0.296	0.280
Y	0.267	0.305	0.276	0.248
Reference CCT: 14000~9000k				

a1				
X	0.248	0.275	0.283	0.264
Y	0.286	0.321	0.305	0.267
Reference CCT: 14000~9000k				

b1				
X	0.283	0.330	0.330	0.287
Y	0.305	0.360	0.339	0.295
Reference CCT: 9000~5600k				

b2				
X	0.287	0.330	0.330	0.296
Y	0.295	0.339	0.318	0.276
Reference CCT: 9000~5600k				

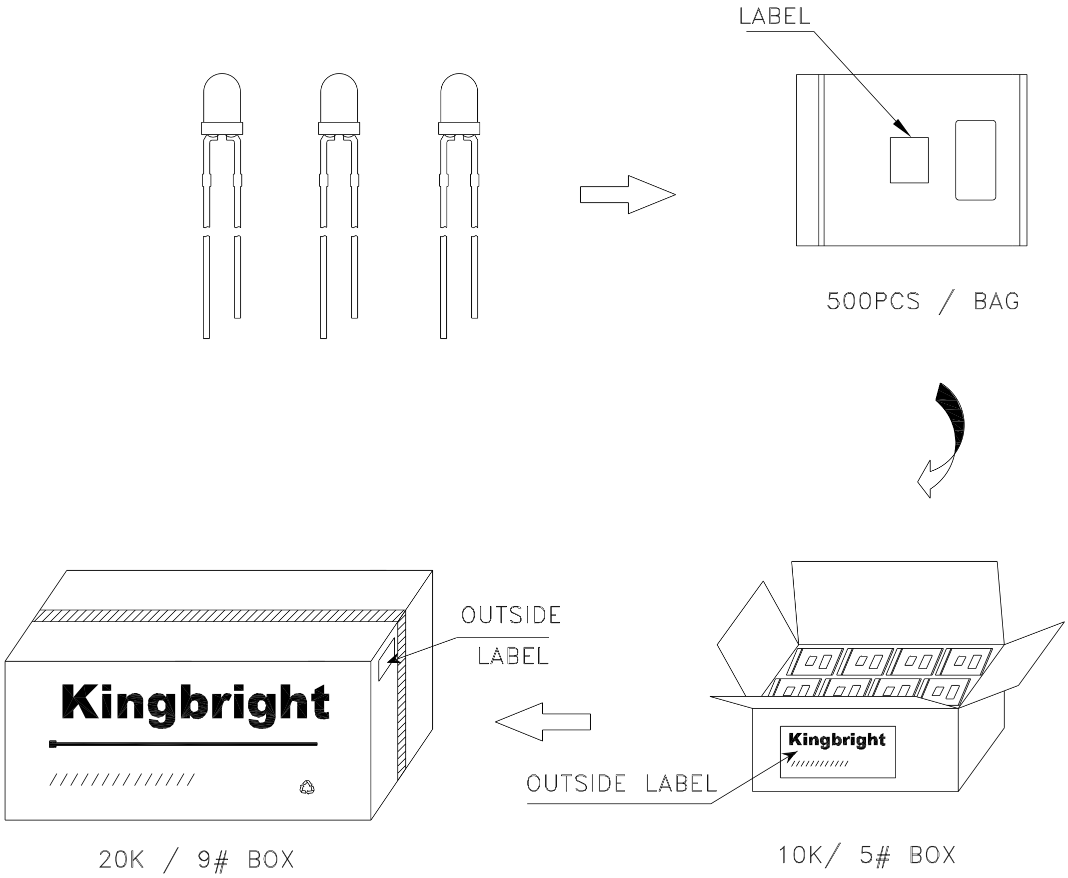
b3				
X	0.275	0.298	0.306	0.283
Y	0.321	0.350	0.332	0.305
Reference CCT: 9000~7000k				

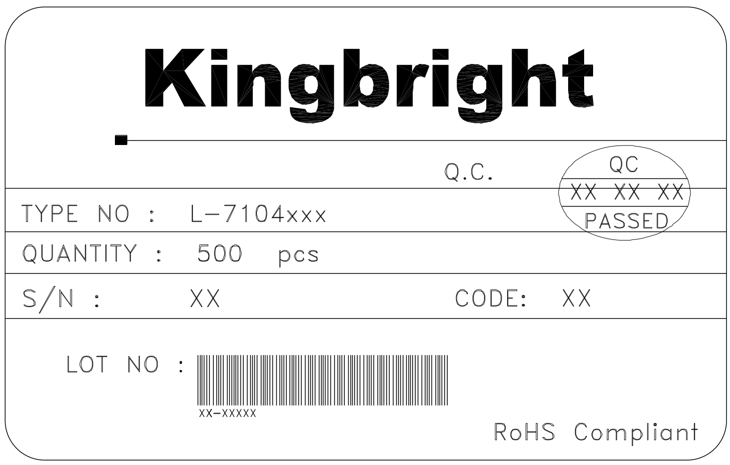
b4				
X	0.298	0.321	0.330	0.306
Y	0.350	0.379	0.360	0.332
Reference CCT: 7600~5600k				

c0				
X	0.330	0.361	0.356	0.330
Y	0.360	0.385	0.351	0.318
Reference CCT: 5600~4600k				

c1				
X	0.321	0.366	0.361	0.330
Y	0.379	0.419	0.385	0.360
Reference CCT: 6000~4600k				

PACKING & LABEL SPECIFICATIONS **L-7104PWC-A**





5mm LEDs

Order code	Manufacturer code	Description
55-1602	L-7113MWC	L-7113MWC 5MM WATER CLEAR_WHITE LED (RC)

Sales: 01206 751166
Sales@rapidelec.co.uk

Technical: 01206 835555
Tech@rapidelec.co.uk

Fax: 01206 751188
www.rapidelectronics.co.uk

L-7113MWC WHITE

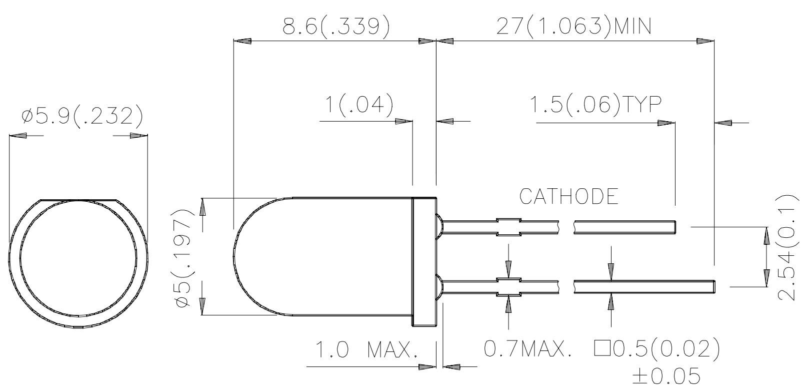
Features

- ●HIGH EFFICIENCY.
- ●WHITE EMISSION,HIGH LUMINOUS INTENSITY.

Description

The source color devices are made with GaN on SiC Light Emitting Diode.
Static electricity and surge damage the LEDS. It is recommended to use a wrist band or anti-electrostatic glove when handling the LEDs.
All devices, equipment and machinery must be electrically grounded.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the lead emerge package.
4. Specifications are subject to change without notice.

Optical Characteristics

Part No.	Dice	Lens Type	Iv (mcd) @20mA		Viewing Angle
			Min.	Typ.	2θ1/2
L-7113MWC	WHITE (GaN)	WATER CLEAR	80	200	20°

Note:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.

Electrical / Optical Characteristics at T_A=25°C

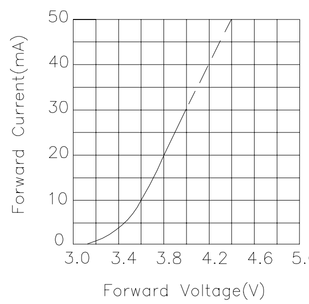
Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
V_F	Forward Voltage	White	3.8	4.5	V	IF=20mA
I_R	Reverse Current	White		10	uA	VR = 5V
X	Chromaticity Coordinates	White	0.40			
Y			0.43			
C	Capacitance	White	65		pF	VF=0V, f =1MHz

Absolute Maximum Ratings at T_A=25°C

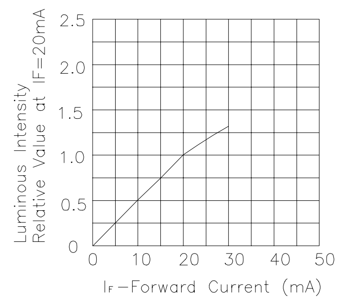
Parameter	White	Units
Power dissipation	105	mW
DC Forward Current	30	mA
Peak Forward Current[1]	150	mA
Reverse Voltage	5	V
Operating Temperature	-40°C To +85°C	
Storage Temperature	-40°C To +85°C	
Lead Solder Temperature[2]	260°C For 5 Seconds	

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 4mm below package base.

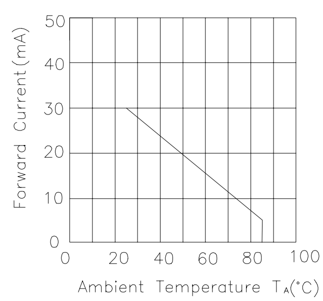
White L-7113MWC



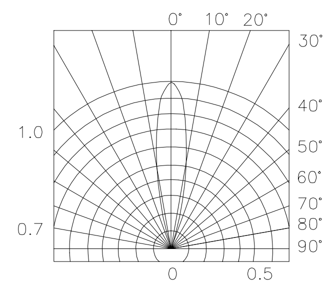
FORWARD CURRENT Vs
FORWARD VOLTAGE



LUMINOUS INTENSITY Vs.
FORWARD CURRENT



FORWARD CURRENT
DERATING CURVE



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APPENDIX B. TECHNICAL SPECIFICATION DOCUMENT

ELECTRONICS & ELECTRICAL ENGINEERING
UNIVERSITY OF GLASGOW
INDIVIDUAL PROJECT 2011-2012

1. Project Planning Document

Name of Student:	**Mario Gancedo Sanz**	
Matric Number:	1103773	
1st Supervisor:	Dr. T. Kelly	Supervisor initials (plan approved): AEK
2nd Supervisor:	Dr. S. Roy	
Project Number:	48	
Title of Project:	Visible Light Data Communications	

Aims of project:

To investigate, in collaboration with Thales Optronics, the use of commercial components in producing a Visible Light Communication (VLC) prototype system as well as its operation.

Workplan and Milestones:

Description of task	Oct/Nov 25 30	December 1 16	January 9 31	February 1 28	March 1 16
Find information and background reading to understand how Visible Light Communication works. *Milestone: Background reading completed.*					
System definition: search suitable devices for the main components of the VLC transmitter (LEDs) and the VLC receiver (Photodiode).					
System testing.					
Write up the final report.					
	Oct/Nov 25 30	December 1 16	January 9 31	February 1 28	March 1 16

Milestones (completion of a significant task) are indicated by △

ELECTRONICS & ELECTRICAL ENGINEERING
UNIVERSITY OF GLASGOW
INDIVIDUAL PROJECT 2011-2012

2. Project Specification

Name of Student:	**Mario Gancedo Sanz**	
Matric Number:	1103773	
1st Supervisor:	Dr. T. Kelly	Supervisor initials (plan approved): AEK
2nd Supervisor:	Dr. S. Roy	
Project Number:	48	
Title of Project:	Visible Light Data Communications	

Topics	**Outcome/Specification**
Background reading:	- Familiarise with VLC technology, know how it works and its applications.
VLC transmitter (Phosphor-based LEDs):	- Look at the main features of LEDs for optical communication: frequency response and power efficiency. - Phosphor bandwidth filtering.
VLC receiver (Photodiode):	- Analyze critical performance parameters of a photodiode: responsivity, dark current and noise-equivalent power.
VLC prototype:	- Test the system and estimate the data rate transfer, bit error rate, maximum transmitter-receiver distance for data transmission...
Writing:	- Write up the final VLC thesis report.