DEVELOPMENT OF A RGB LED BASED SPECTRAL TUNABLE LIGHT SOURCE FOR IN-HOUSE PLANTATION

A thesis submitted in partial fulfillment of the requirement for the degree of

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ILLUMINATION ENGINEERING

Submitted by

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RECOMMENDATION CERTIFICATE

This is to certify that the thesis entitled **" DEVELOPMENT OF A RGB LED BASED SPECTRAL TUNABLE LIGHT SOURCE FOR IN-HOUSE PLANTATION "** submitted by **ABHISHEK SARKAR**, (Examination Roll No. M4ILN23003, Registration No.160182 of 2020-2021) of this University in partial fulfillment of requirements for the award of the degree of Master of Engineering in Illumination Engineering, Electrical Engineering Department, is a bonafide record of the work carried out by him under my guidance and supervision.

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CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a creditable study in the area of Illumination Engineering carried out and presented by **ABHISHEK SARKAR, in a manner of satisfactory warrants its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undesigned does not necessarily endorse or approve the thesis only for the purpose for which has been submitted.**

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I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Illumination Engineering studies.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by thesis rules and conduct, I have fully cited and referenced all material and results which are not original to this work.

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1 INTRODUCTION

1.1 General Overview

The development of an RGB LED-based separately tunable light source for in-house plantations represents an innovative approach to indoor gardening and horticulture. This technology harnesses the power of light-emitting diodes (LEDs) to provide customizable and optimal lighting conditions for plants' growth and development.

In-house plantation, also known as indoor gardening or urban farming, has gained significant popularity in recent years due to its numerous benefits. It allows individuals to cultivate plants within the confines of their homes or other indoor spaces, overcoming limitations such as limited outdoor space, unfavorable weather conditions, or urban living environments.

The RGB LED-based light source for in-house plantation takes advantage of the different wavelengths of light emitted by red, green, and blue LEDs. By combining and adjusting the intensity of these primary colors, the light source can create a wide spectrum of light that closely mimics natural sunlight. This tunability enables growers to provide plants with specific light conditions tailored to their growth stages, optimizing photosynthesis, and maximizing plant productivity.

The benefits of this technology extend beyond providing adequate light for plant growth. The separate tunability of the light source allows for precise control over the light spectrum, which can influence various plant characteristics, such as leaf size, color, and nutrient content. Additionally, the energy-efficient nature of LED lighting minimizes power consumption and reduces heat generation, making it an environmentally friendly choice for in-house plantation systems.

The development of an RGB LED-based separately tunable light source for in-house plantations holds great potential for revolutionizing indoor gardening practices. It offers a sustainable and efficient solution for individuals interested in cultivating plants in indoor environments, providing them with the means to create optimal growing conditions and promote healthy plant growth throughout different stages of the plant's life cycle.

1.2 Objective

The objective of the development of an RGB LED-based separately tunable light source for in-house plantations is to create a technologically advanced lighting system that caters specifically to the needs of indoor gardening and horticulture. The key objectives include:

1. Optimal Plant Growth: The primary objective is to design a lighting system that can provide the ideal light spectrum for different plant growth stages. By adjusting the intensity and combination of red, green, and blue LEDs, the light source aims to mimic natural sunlight and promote photosynthesis, leading to healthy plant growth, improved yield, and enhanced plant quality.

2. Customizable Lighting Conditions: The light source should offer separate tunability, allowing growers to customize the light spectrum according to the specific requirements of different plant species. This flexibility ensures that plants receive the right amount and quality of light, tailored to their unique needs, promoting optimal growth and development.

3. Energy Efficiency: An important objective is to develop an energy-efficient lighting solution that minimizes power consumption while delivering sufficient light output for plants.

By utilizing LED technology, the light source aims to reduce energy usage compared to traditional lighting systems, making it sustainable and cost-effective for indoor gardening applications.

4. Environmental Sustainability: The development of the RGB LED-based light source also aims to contribute to environmental sustainability. By minimizing heat generation and incorporating energy-efficient components, the system reduces greenhouse gas emissions associated with energy consumption, making it an eco-friendly choice for indoor gardening practices.

5. User-Friendly Design: Another objective is to create a user-friendly light source that is easy to install, operate, and maintain. The design should be user-centric, considering factors such as ease of adjustment, control interfaces, and durability to ensure a seamless experience for growers of varying skill levels.

6. Research and Innovation: The development of this light source aims to contribute to ongoing research and innovation in the field of indoor gardening. By providing a platform for experimentation and data collection, the system can support further studies on the effects of the light spectrum on plant growth, enabling advancements in the field of horticulture.

Overall, the objective of developing an RGB LED-based spectrally tunable light source for in-house plantation is to revolutionize indoor gardening practices by providing growers with a sophisticated and customizable lighting solution that enhances plant growth maximizes productivity, and promotes sustainability.

1.3 LITERATURE REVIEW

Naichia Yeh Naichia Yeh Develop High-brightness LEDs—Energy-efficient lighting sources and their potential in indoor plant cultivation. With the impacts of climate change, issues such as more frequent and serious droughts, floods, and storms as well as pests and diseases are becoming more serious threats to agriculture. These threats along with the shortage of food supply make people turn to indoor and urban farming (such as vertical farming) for help. With proper lighting, indoor agriculture eliminates weather-related crop failures due to droughts and floods to provide year-round crop production, which assists in supplying food in cities with surging populations and in areas of severe environmental conditions. The use of light-emitting diodes marks great advancements over existing indoor agricultural lighting. LEDs allow the control of spectral composition and the adjustment of light intensity to simulate the changes in sunlight intensity during the day. They have the ability to produce high light levels with low radiant heat output and maintain useful light output for years. LEDs do not contain electrodes and thus do not burn out like incandescent or fluorescent bulbs that must be periodically replaced. Not to mention that incandescent and fluorescent lamps consume a lot of electrical power while generating heat, which must be dispelled from closed environments such as spaceships and space stations.

Md Momtazur Rahman, David Luke Field, Mohammad Khairul Basher study LED Illumination for High-Quality High-Yield Crop Growth in Protected Cropping Environments In contrast to fluorescent lamps and high-power sodium lamps, the use of light-emitting diode (LED) lamps enables the control of not only photosynthetic photon flux density (PPFD) at the plant level but also the relative spectral photon flux density distribution (RSPD) of light because of the variety, even at different times of day, of producible light emitted by LEDs of various types. The effects of the spectral photon flux density on plant growth and morphology have been investigated using several LEDs and plant species. However, few studies on lighting methods with time-varying PPFD or RSPD have been published to date. In this paper, we summarize the effects of time-varying PPFD on the net photosynthetic rate (Pn) and those of time-varying RSPD on plant growth and morphology. Detailed modeling studies have been conducted on the reactions of the photosynthetic pathway under time-varying PPFD at a cycle of milliseconds to seconds. The results of these modeling studies and actual measurements of Pn under pulsed light clearly indicate that pulsed light is not advantageous to improve Pn. Although the integrated PPFD of blue and red light was unchanged, the growth of leaf lettuce was promoted by asynchronous irradiation with blue light and red light compared with growth under simultaneous irradiation. Blue-light monochromatic irradiation promotes leaf elongation through leaf expansion as a primary factor in the enhancement of plant growth. In addition, changes in leaf photosynthetic capacity caused by blue-light monochromatic irradiation may be involved in plant growth promotion. An increasing number of studies have investigated the effects of time-varying RSPD on plants. However, the mechanisms underlying these effects remain to be elucidated.

Zhonghua Bian, Steven Grundy Chungui Lu Uncovering study LED light effects on plant growth: New angles and perspectives LED light for improving plant growth, nutrition, and energy-use efficiency. Light supplementation can increase crop yield in greenhouses by promoting photosynthesis and plant growth. However, the high energy costs associated with light supplementation are a predominant factor that limits the development and profit improvement of controlled environment agriculture. Light-emitting diodes (LEDs) are a promising technology that has tremendous potential to improve irradiance efficiency and replace traditionally used horticultural lighting. Compared with traditional light sources (e.g., high-pressure sodium lamps and metal halide lamps) used in crop production, LEDs have distinct advantages, such as their small size, long lifetime, and high photoelectric conversion efficiency. Most importantly, as a monochromatic light source, the spectrum of LEDs can be adjusted based on plant growth requirements. This project aimed to investigate energy-use efficiency, vegetable nutrition, and photosynthesis improvement of light supplementation in a protected horticulture system. In the initial phase, the effects of LED light on plant growth and light-use efficiency for pak choi and photosynthetic performance were investigated. The results showed that the highest fresh and dry weight and leaf area were observed under red and blue LED light, with the blue light percentage at 23 Percent. Compared with fluorescent lamps (FL) with photosynthetic photon flux density (PPFD) at 220 mol m-2 s-1, the light-use efficiency increased by 55, 114 and 115 for mixed red and blue LEDs with PPFD at 100, 150, and 220 mol m-2 s-1, respectively. Monochromatic red- and blue-light LEDs resulted in significant decreases in Pn of tomato plants, but the stomatal conductance (Gs) for monochromatic blue LEDs was higher than that for FL. The effect of light spectrum composition on lettuce nutrition quality was also studied. Continuous light with combined red, green, and blue LEDs exhibited a remarkable decrease in nitrate. Moreover, continuous LED light for 24 h significantly increased phenolic compound content and free-radical scavenging capacity in lettuce leaf.

Md Momtazur Rahman, David Luke Field, Mohammad Khairul Basher study LED Illumination for High-Quality High-Yield Crop Growth in Protected Crop-

ping Environments Vegetables and herbs play a central role in the human diet due to their low fat and calorie content and essential antioxidant, phytochemicals, and fiber. It is well known that the manipulation of light wavelengths illuminating the crops can enhance their growth rate and nutrient contents. To date, it has not been easy to generalize the effects of LED illumination because of the differences in the plant species investigated, the measured traits, the way wavelengths have been manipulated, and the plants' growing environments. In order to address this gap, we undertook a quantitative review of LED manipulation in relation to plant traits, focusing on vegetables and herbs. Here, we use standardized measurements of biomass, antioxidant, and other quantitative characteristics together with the whole range of the photosynthetic photon flux density (PPFD). Overall, our review revealed support for the claims that red and blue LED illumination is more reliable and efficient than full spectrum illumination and increases the plant's biomass and nutritional value by enhancing the photosynthetic activity, antioxidant properties, phenolic, and flavonoid contents. Although LED illumination provides an efficient way to improve yield and modify plant properties, this study also highlights the broad range of responses among species, varieties traits, and the age of plant material.

1.4 Organization of the Thesis Work

1. Provides a brief general introduction.

2. Light Spectrum and Plant Responses: Discuss the role of different light wavelengths (red, green, blue, etc.) in photosynthesis, photomorphogenesis, and plant growth. Present research findings on the effects of specific light spectra on plant development, yield, and quality.

3. LED Lighting in Horticulture: Explore the advancements and advantages of using LED lighting for plant cultivation, including energy efficiency, long lifespan, adjustable spectrum, and targeted light output.

4. Tunable LED Systems: Examine previous studies and developments related to separately tunable LED lighting systems for indoor gardening. Discuss the methods used for adjusting the light spectrum, such as dimming, color mixing, and spectral control techniques.

5. Plant-Specific Lighting Requirements: Analyze the specific lighting requirements for different plant species or growth stages, highlighting the optimal light spectra and intensities needed for various crops.

6. System Design and Control: Review the design considerations for an RGB LED-based separately tunable light source, including LED selection, thermal management, electrical design, and control mechanisms. Discuss the various control interfaces and automation options available for managing the light source.

7. Performance Evaluation

8. Case Studies and Experimental Results: Present case studies or experimental findings from previous research works that have investigated the effectiveness of RGB LED-based separately tunable light sources for in-house plantations. Discuss the outcomes, limitations, and potential areas for further research.

9. Conclusion and Future Directions: Summarize the key findings and conclusions from the literature review, and propose potential avenues for future research and development in the field of RGB LED-based separately tunable light sources for in-house plantation.

2 Electromagnetic Wave

2.1 The general concept of Electromagnetic Wave

Electromagnetic waves (EM waves) are a form of energy propagation that consists of oscillating electric and magnetic fields. They are generated by the acceleration or oscillation of charged particles, such as electrons.
EM waves are characterized by their wavelength (lamda) and frequency (f). The wavelength represents the distance between consecutive peaks or troughs of the wave, while the frequency indicates the number of complete oscillations that occur per unit time. The relationship between wavelength and frequency is given by the equation: c = f, where c is the speed of light in a vacuum (approximately $3 \times 10^8 meters per second$).

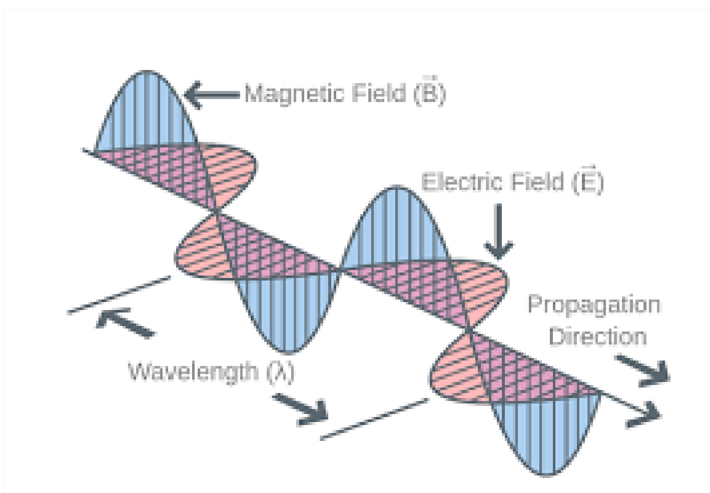

Figure 1: Electromagnetic waves

The electromagnetic spectrum encompasses a wide range of EM waves, classified based on their wavelengths or frequencies. This spectrum includes radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Each segment of the spectrum has different properties and applications.

EM waves have several fundamental characteristics:

1. Electromagnetic Fields: EM waves consist of two perpendicular fields - an electric field and a magnetic field. These fields oscillate in phase with each other and are perpendicular to the direction of wave propagation.

2. Transverse Nature: EM waves are transverse waves, meaning the oscillations occur perpendicular to the direction of wave propagation. This is in contrast to longitudinal waves, where the oscillations are parallel to the wave's direction.

3. Speed of Light: EM waves travel at the speed of light, denoted by 'c.' In a vacuum, this speed is constant and approximately 3×10^8 meters per second. The speed of EM waves can vary when passing through different media. 4. Energy Transfer: EM waves carry energy as they propagate through space. The intensity of the wave, which represents the amount of energy carried per unit area, decreases with distance from the source.

5. Interaction with Matter: EM waves can interact with matter in various ways. Depending on the wavelength, they can be absorbed, transmitted, or reflected by different materials. This property is the basis for various applications such as communication, imaging, and heating.

EM waves have numerous practical applications in everyday life and scientific fields. Radio waves are used for communication, television, and wireless technology. Microwaves are utilized in cooking, radar systems, and satellite communications. Infrared radiation is employed in night vision devices, remote sensing, and thermal imaging. Visible light enables vision

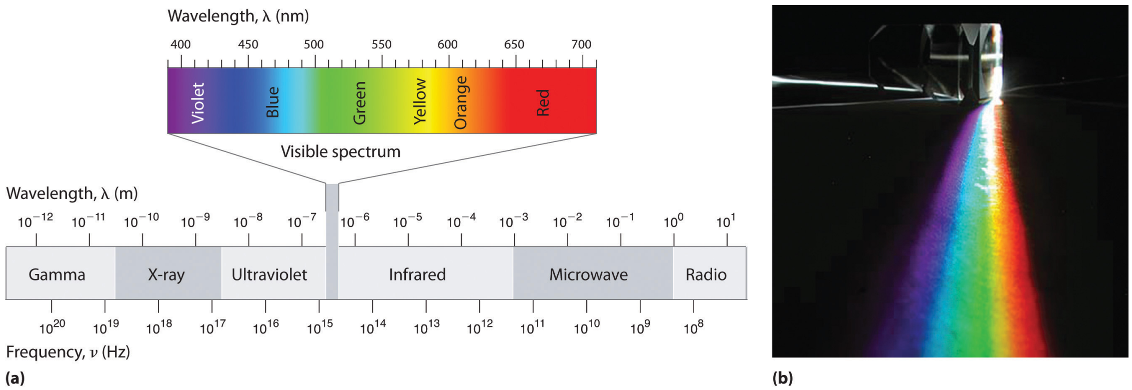

Figure 2: Electromagnetic Waves Spectrum

and is used in optical technologies. X-rays and gamma rays find applications in medical imaging, cancer treatment, and industrial inspection.

Overall, electromagnetic waves play a vital role in our understanding of the physical world and have a wide range of practical applications across different domains.

2.2 Electromagnetic wave for plant growth

Electromagnetic (EM) waves have several applications in the context of plants and agriculture. Here are a few ways EM waves are relevant to plants:

Photosynthesis: EM waves in the visible light spectrum (wavelengths approximately 400-700 nanometers) are essential for photosynthesis in plants. Chlorophyll, the pigment responsible for capturing light energy, absorbs specific wavelengths of light to drive the photosynthetic process. The energy from absorbed light is used to convert carbon dioxide and water into glucose and oxygen, providing energy for plant growth.

Growth and Development: Certain aspects of plant growth and development are influenced by different regions of the EM spectrum. For example, red and far-red light (wavelengths around 660 and 730 nanometers, respectively) play a role in regulating processes such as seed germination, stem elongation, flowering, and fruit ripening. The exposure to specific wavelengths or ratios of light can be manipulated to optimize plant growth and yield in controlled environments.

Indoor and Vertical Farming: In indoor and vertical farming systems, artificial lighting is often used to provide the necessary light for plant growth. LED (Light Emitting Diode) technology allows for precise control of light spectra, including the ability to tailor the ratios of red, blue, and other wavelengths. By providing the right combination of light wavelengths, indoor farming systems can optimize photosynthesis and promote plant growth while minimizing energy consumption.

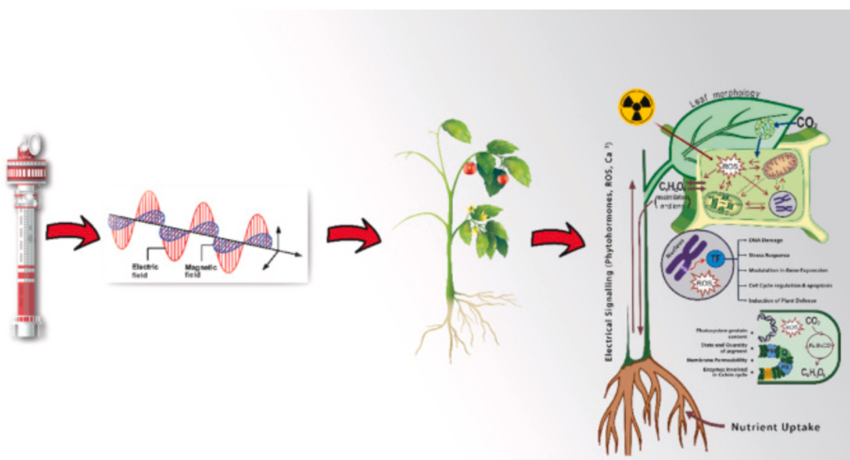

Figure 3: Electromagnetic wave for plant growth

Remote Sensing: Remote sensing techniques utilize various parts of the EM spectrum, including visible, infrared, and microwave wavelengths, to monitor plant health and vegetation characteristics from a distance. Sensors on satellites and aircraft can collect data on vegetation indices, such as NDVI (Normalized Difference Vegetation Index), which provide insights into plant vigor, chlorophyll content, and overall plant health. This information aids in agricultural management, crop monitoring, and assessing environmental conditions.

Disease and Stress Detection: Some EM wave-based technologies can detect plant diseases and stress conditions. For instance, thermal imaging using infrared radiation can identify temperature anomalies in plants, indicating areas of stress or disease infection. Similarly, hyperspectral imaging, which captures information across a broad range of wavelengths, can reveal subtle changes in leaf reflectance that may be indicative of plant stress or disease.

These are just a few examples of how electromagnetic waves play a role in plant biology, cultivation, and monitoring. By understanding and manipulating the interaction between EM waves and plants, researchers and agricultural practitioners can enhance crop productivity, optimize resource utilization, and develop sustainable farming practices.

3 LED Technology

3.1 Light Emitting Diod (LED)

LED stands for Light Emitting Diode. It is a semiconductor device that emits light when an electric current passes through it. LEDs are widely used in various applications due to their energy efficiency, long lifespan, compact size, and versatility.

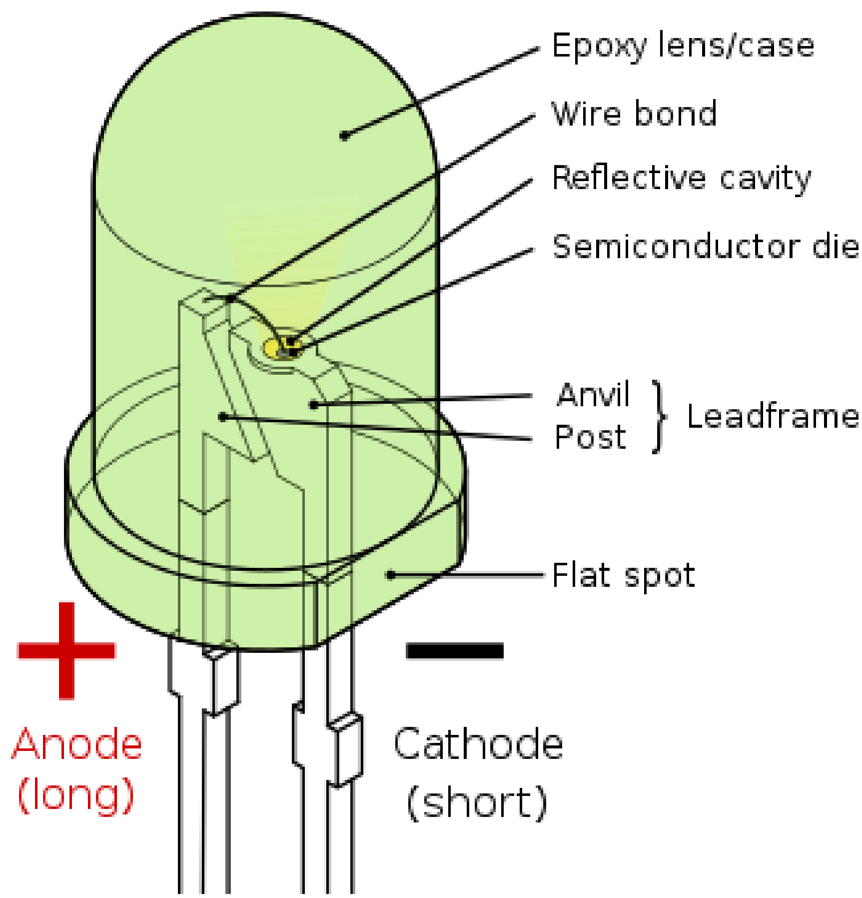

Figure 4: LIGHT EMITTING DIOD

The basic structure of an LED consists of semiconductor material, usually made of gallium arsenide (GaAs), gallium phosphide (GaP), or gallium nitride (GaN). The semiconductor material is doped with impurities to create a region with excess electrons (N-type) and another region with a deficit of electrons or excess of positively charged "holes" (P-type). The junction between these regions is called a P-N junction.

When a voltage is applied across the P-N junction in the forward direction (anode connected to the P-side and cathode connected to the N-side), electrons from the N-side and holes from the P-side combine at the junction, releasing energy in the form of photons. This process is known as recombination, and the energy of the photons emitted depends on the bandgap of the semiconductor material.

LEDs are available in a wide range of colors, including red, green, blue, yellow, amber, and white. The color of the emitted light depends on the specific semiconductor material used and the dopants added during the manufacturing process.

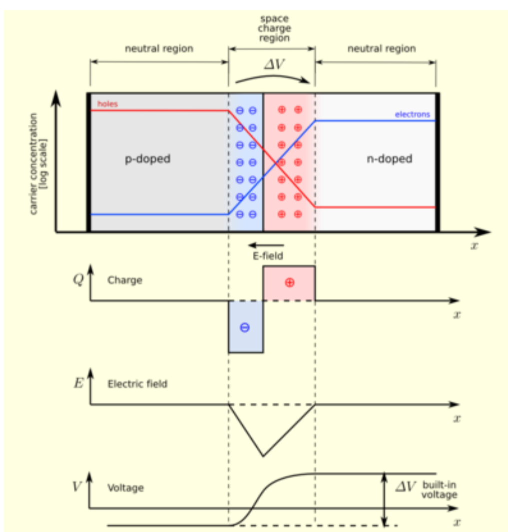

Figure 5: P-N junction

LEDs offer several advantages over traditional lighting sources. They are highly energy efficient, converting a significant portion of electrical energy into light. Compared to incandescent bulbs, LEDs produce very little heat, reducing energy wastage. LEDs also have a long lifespan, typically lasting tens of thousands of hours, making them ideal for long-term use and reducing maintenance costs.

LEDs have revolutionized various industries and applications. They are commonly used in lighting fixtures for residential, commercial, and industrial purposes. LEDs are also found in electronic displays, such as televisions, computer monitors, and smartphones. Additionally, they are used in automotive lighting, traffic signals, signage, and many other applications.

The development of RGB LEDs, which combine red, green, and blue LEDs in a single package, enables the creation of a wide range of colors by varying the intensity of each primary color. RGB LEDs are widely used in decorative lighting, stage lighting, and color-changing applications.

Overall, LEDs are a fundamental technology that has transformed the lighting industry and offers numerous benefits in terms of energy efficiency, durability, and versatility in various applications.

3.2 Physics of Light Generation from Light-Emitting Diode

The physics behind light generation in a Light Emitting Diode (LED) involves a process known as electroluminescence. It occurs within the LED's semiconductor material and is governed by the principles of quantum mechanics. Here is an overview of the physics involved.

Energy Bands: The LED's semiconductor material, such as gallium arsenide (GaAs), has a specific energy band structure. The valence band contains electrons in their lowest energy state, while the conduction band is the higher energy band where electrons can move freely.

Bandgap: The energy gap between the valence band and the conduction band is known as the bandgap. In LEDs, this bandgap determines the color of light emitted. Different semiconductor materials with varying band gaps can produce different colors of light.

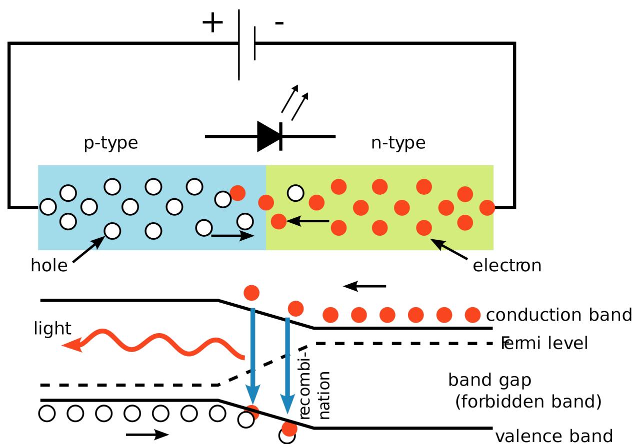

Figure 6: Caption

Injection of Electrons and Holes: When a forward voltage is applied across the LED (positive voltage applied to the anode and negative voltage applied to the cathode), electrons from the N-type region (excess electrons) and holes from the P-type region (deficiency of electrons) are injected into the depletion region or the P-N junction.

Recombination: Electrons and holes that are injected into the depletion region can recombine at the P-N junction. When an electron from the conduction band recombines with a hole from the valence band, the electron loses energy. This energy is emitted in the form of a photon.

Photon Emission: The energy of the emitted photon corresponds to the energy difference between the conduction and valence bands, which is determined by the bandgap of the semiconductor material. Different bandgap energies result in different colors of light. For example, a larger bandgap corresponds to higher energy photons in the blue or ultraviolet range, while a smaller bandgap corresponds to lower energy photons in the red or infrared range.

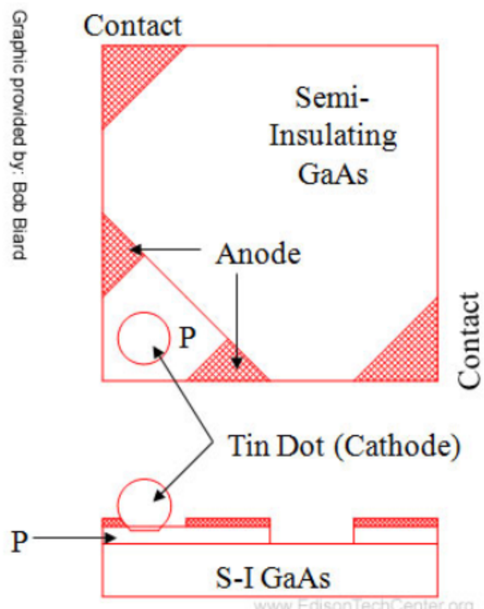

Figure 7: GaAs

Releasing Heat: During the recombination process, some energy is also released as heat. This is why LEDs are more energy-efficient compared to traditional incandescent bulbs, which produce a significant amount of heat.

External Factors: The efficiency and characteristics of LED light generation can be influenced by external factors such as temperature, current density, and material quality. For example, higher temperatures can decrease LED efficiency, while higher current densities can cause non-radiative recombination, reducing light output.

By carefully selecting semiconductor materials and optimizing the design and fabrication process, LEDs can be engineered to emit light of specific wavelengths and colors. This ability, along with their efficiency and long lifespan, has made LEDs a versatile and widely used lighting technology in various applications.

4 LED Lighting and Plant

4.1 LED Lighting in Horticulture

LED (Light Emitting Diode) lighting has gained significant popularity and recognition in horticulture due to its numerous advantages and benefits for plant growth. Here are some key aspects of LED lighting in horticulture:

Energy Efficiency: LED lighting is highly energy-efficient, converting a large portion of electrical energy into usable light for plants. LEDs can produce specific wavelengths of light that are most effective for photosynthesis, resulting in optimized energy utilization.

Tailored Light Spectrum: LED technology allows for precise control over the light spectrum emitted. By selecting specific wavelengths, such as blue (400-500 nm), red (600-700 nm), and far-red (700-800 nm), LED lighting can be customized to match the exact requirements of different plant growth stages. This spectral control enhances photosynthesis, flowering, fruiting, and overall plant development.

Greater Light Output and Directionality: LED fixtures provide high light output in a targeted manner, delivering light directly to the plants without wasting energy on unnecessary areas. LEDs also have the advantage of being easily adjustable and adaptable to different plant canopies, ensuring uniform light distribution.

Longer Lifespan: LEDs have a longer operational lifespan compared to traditional lighting technologies. They can last for tens of thousands of hours, reducing the need for frequent replacements and maintenance, and lowering overall costs.

Reduced Heat Generation: Unlike other lighting technologies, LEDs produce minimal heat, allowing for closer proximity to plants without causing damage. This proximity enables growers to place LED fixtures at the ideal distance, maximizing light absorption by plants and minimizing energy waste.

Compact Design and Flexibility: LED fixtures have a compact size and are available in various shapes and configurations, making them highly versatile in indoor horticultural applications. They can be easily integrated into different grow systems, such as vertical farming, hydroponics, and greenhouse setups.

Controllability and Automation: LED lighting systems can be easily controlled and automated, providing precise light intensity, duration, and spectral composition. This level of control allows growers to mimic natural daylight cycles, adjust lighting parameters based on specific plant requirements, and optimize growth conditions.

Environmental Sustainability: LED lighting is environmentally friendly, as it consumes less energy, produces fewer greenhouse gas emissions, and contains no harmful substances like mercury. This makes LEDs a more sustainable choice for indoor horticulture, aligning with the principles of eco-friendly cultivation practices.

Due to these advantages, LED lighting has become the preferred choice for various horticultural applications, including commercial greenhouse cultivation, indoor vertical farms, urban gardening, and research facilities. The versatility, energy efficiency, and customizable features of LED lighting contribute to improved plant growth, increased crop yields, and enhanced productivity in horticultural settings.

4.2 Explore the advancements and advantages of using LED lighting for plant cultivation

LED (Light Emitting Diode) lighting has revolutionized the field of plant cultivation, offering numerous advancements and advantages over traditional lighting methods. Here are some key advancements and benefits of using LED lighting for plant cultivation:

Energy Efficiency: LED lighting is highly energy-efficient, converting a large portion of electrical energy into usable light for plants. Compared to traditional lighting technologies such as incandescent or fluorescent lamps, LEDs consume significantly less energy, resulting in reduced electricity costs and environmental impact.

Tailored Light Spectrum: LED technology allows for precise control over the light spectrum emitted. By selecting specific wavelengths, growers can provide plants with the ideal combination of red, blue, and other colors of light that promote specific growth stages, such as vegetative growth, flowering, or fruiting. This spectral control enhances photosynthesis and overall plant development.

Increased Light Output and Directionality: LEDs produce high-intensity light output with the ability to focus it directly onto plants. This targeted light delivery minimizes wasted energy and ensures efficient light absorption by the plants. It also allows for uniform light distribution across the entire plant canopy, promoting even growth and minimizing shading effects.

Enhanced Growth and Yield: The precise control of light spectrum and intensity provided by LED lighting systems can significantly enhance plant growth and yield. By optimizing the light conditions for specific crops, growers can stimulate plant growth, shorten cultivation cycles, and improve overall productivity. LEDs have been shown to promote better plant morphology, increased biomass production, and improved nutritional quality in various crops.

Customizable Lighting Programs: LED lighting systems offer flexibility in creating customizable lighting programs. Growers can simulate natural daylight cycles, adjust lighting parameters based on specific crop requirements, and even create dynamic lighting scenarios to stimulate specific physiological responses in plants. This level of control allows for fine-tuning and optimization of growth conditions for different plant species.

Longer Lifespan and Durability: LEDs have a longer operational lifespan compared to traditional lighting sources. They can last for tens of thousands of hours, reducing the need for frequent bulb replacements. LEDs are also more durable, as they are solid-state devices that are resistant to shocks, vibrations, and temperature fluctuations, making them ideal for horticultural environments.

Heat Management: LED lighting produces significantly less heat compared to traditional lighting technologies like high-pressure sodium (HPS) lamps. This reduces the risk of heat stress and allows for closer positioning of the lights to the plants without causing damage. It also helps in maintaining optimal growing temperatures, especially in indoor cultivation systems.

Environmental Sustainability: LED lighting is environmentally friendly, consuming less energy and generating fewer greenhouse gas emissions compared to conventional lighting methods. LEDs do not contain hazardous substances like mercury, making them safer for the environment and human health. This aligns with the principles of sustainable and eco-friendly cultivation practices.

The advancements and advantages of LED lighting have made it the preferred choice for a wide range of plant cultivation applications, including commercial greenhouse farming, vertical farming, indoor gardening, and research facilities. With their energy efficiency, spectral control, customizability, and positive impact on plant growth, LEDs have transformed the way we cultivate plants, leading to improved crop quality, increased yields, and more sustainable agriculture practices.

5 Color-changing LED systems

5.1 Color-Tunable or color-changing LED systems

Tunable LED systems, also known as color-tunable or color-changing LED systems, are lighting solutions that allow users to adjust the color temperature and intensity of the emitted light. Unlike traditional lighting fixtures that produce a fixed color, tunable LED systems provide flexibility and customization options for different applications and environments.

Here are some key aspects of tunable LED systems:

Color Temperature Control: Tunable LED systems can adjust the color temperature of the light output, typically measured in Kelvin (K). Lower color temperatures (around 2700-3000K) produce warm white light similar to incandescent bulbs, while higher color temperatures (5000-6500K) create cool white light similar to daylight. By adjusting the color temperature, users can create different moods or adapt to different activities.

Color Rendering Index (CRI): CRI measures how accurately a light source renders colors compared to natural light. High-CRI tunable LED systems provide better color reproduction, making them suitable for applications where color accuracy is important, such as art galleries or retail environments.

Dimming and Intensity Control: Tunable LED systems often offer dimming capabilities, allowing users to adjust the brightness of the light output. This feature is particularly useful for creating different ambiance levels or conserving energy when full brightness is not required.

Control Systems: Tunable LED systems can be controlled using various methods, including manual controls such as wall-mounted switches or remote controls, as well as more advanced options like smartphone apps or centralized control systems. These control systems enable users to adjust color temperature, and brightness and even create dynamic lighting scenes or schedules.

Applications: Tunable LED systems find applications in a wide range of settings, including residential, commercial, and architectural lighting. They are used in homes, offices, hotels, restaurants, museums, theaters, and other spaces where lighting aesthetics and functionality are crucial.

Health and Well-being: Tunable LED systems are often used in lighting designs that consider the impact of lighting on human health and well-being. By adjusting color temperature and intensity, these systems can simulate natural lighting conditions, promoting better sleep patterns, productivity, and overall well-being.

Tunable LED systems provide versatility and adaptability in lighting design, allowing users to create customized lighting environments based on their preferences and specific needs.

5.2 DC 12V-24V 8A LED Bulb Dimmer Switch Brightness Controller

The DC 12V-24V 8A LED Bulb Dimmer Switch Brightness Controller is a device designed to control the brightness of LED bulbs or LED strips operating on DC power between 12V and 24V. It allows users to adjust the intensity of the light output according to their preferences or specific lighting requirements. Here are some key features and functionalities of this dimmer switch:

Input Voltage Range: The dimmer switch is compatible with DC power sources ranging from

12V to 24V. This makes it suitable for various applications where low-voltage LED lighting is used, such as automotive lighting, marine lighting, or off-grid lighting systems.

Current Capacity: The dimmer switch has a maximum current handling capacity of 8A, which means it can handle LED bulbs or LED strips that draw a current up to 8 amps. It is important to ensure that the total current drawn by the LEDs connected to the dimmer switch does not exceed this limit.

Brightness Control: The dimmer switch allows users to adjust the brightness level of the connected LED bulbs or LED strips. This can be achieved by either rotating a physical knob or using buttons or touch-sensitive controls, depending on the specific design of the dimmer switch.

Compatibility: The dimmer switch is specifically designed for use with LED bulbs or LED strips. It may not be compatible with other types of lighting fixtures, such as incandescent bulbs or fluorescent lights, which require different types of dimming mechanisms.

Wiring and Installation: The dimmer switch typically requires wiring connections between the power supply, the dimmer switch itself, and the LED bulbs or LED strips. It is important to follow the manufacturer's instructions and ensure proper electrical connections to ensure safe and reliable operation.

Overload and Short Circuit Protection: Some dimmer switches may include built-in protection mechanisms to prevent damage due to overloading or short circuits. These features help protect the connected LEDs and the dimmer switch itself from potential electrical faults.

When using the DC 12V-24V 8A LED Bulb Dimmer Switch Brightness Controller, it is important to verify the compatibility of the switch with the specific LED bulbs or LED strips you are using. Additionally, adhere to the manufacturer's guidelines and safety precautions to ensure proper installation and operation of the dimmer switch.

5.2.1 DC 12V-24V 8A LED Bulb Dimmer Switch Brightness Controller Circuit

The circuit for a DC 12V-24V 8A LED bulb dimmer switch brightness controller can vary depending on the specific design and manufacturer. However, I can provide you with a basic circuit diagram that can be used as a reference for building such a controller. Here's a simplified circuit diagram: "'

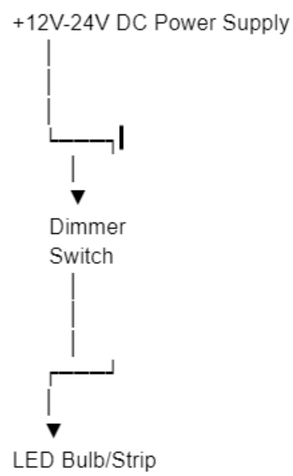

Figure 8: Rough Sketch

In this basic circuit, the power supply provides the DC voltage (ranging from 12V to 24V) to the dimmer switch. The dimmer switch controls the amount of voltage passed to the LED bulb or LED strip, thereby adjusting the brightness.

The dimmer switch typically consists of a potentiometer (variable resistor) or other electronic components that allow the user to adjust the voltage or current flowing to the LEDs. By rotating the knob or using the control mechanism provided by the switch, the user can

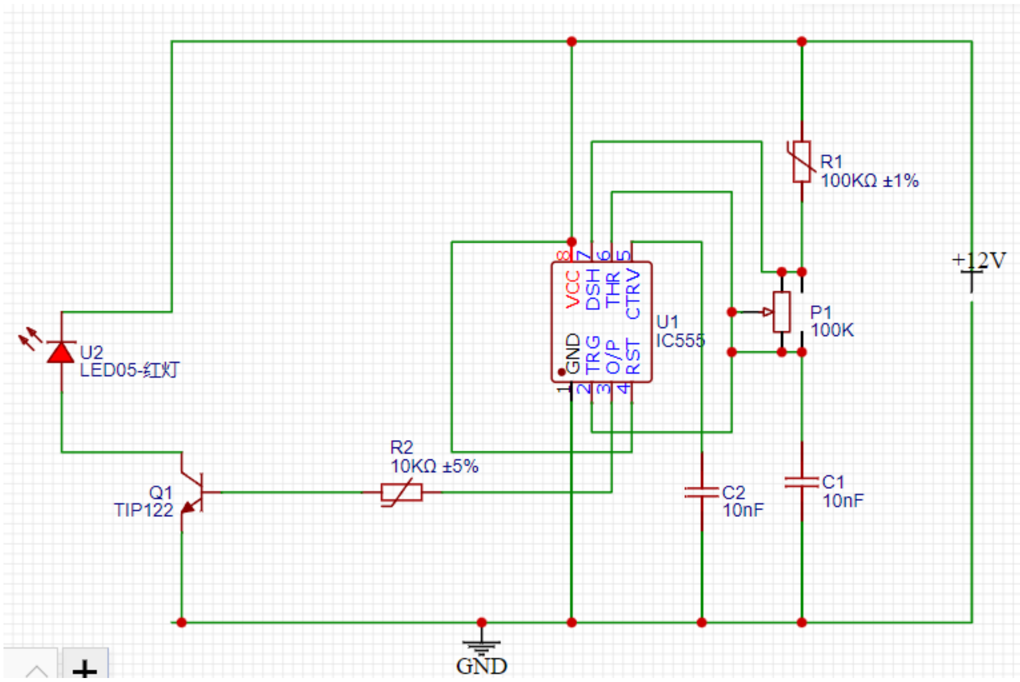

Figure 9: DC 12V-24V 8A LED Bulb Dimmer Switch Brightness Controller Circuit

increase or decrease the brightness of the LEDs.

It's important to note that more complex dimmer switch circuits may include additional components like transistors, operational amplifiers, or microcontrollers to provide more advanced features, such as smoother dimming control or protection against overloading and short circuits. The exact circuitry and components used may vary based on the specific product or manufacturer.

When implementing a circuit like this, it's crucial to ensure proper electrical connections, use suitable components rated for the voltage and current requirements, and follow safety guidelines. If you are not experienced with electronics, it's recommended to consult the manufacturer's instructions or seek assistance from a qualified individual.

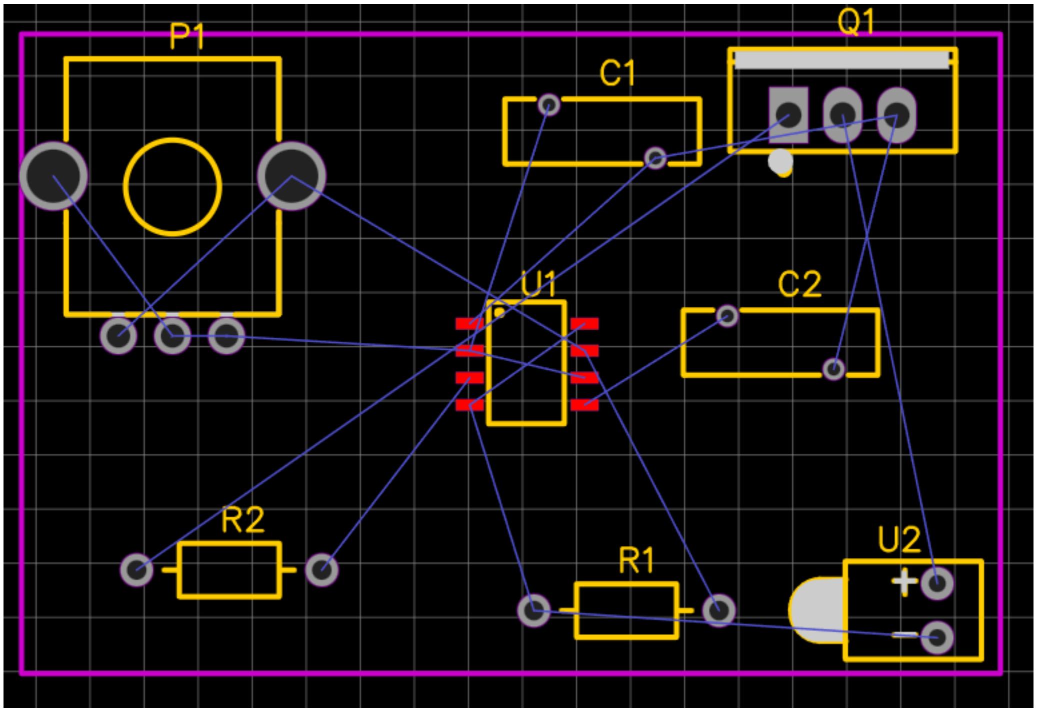

Figure 10: DC 12V-24V 8A LED Bulb Dimmer Switch Brightness Controller PCB Circuit

5.2.2 IC555

The IC555, also known as the 555 timer IC (Integrated Circuit), is a widely used and versatile timer/oscillator IC that has been around for several decades. It was introduced by Signetics Corporation in 1971 and has since become one of the most popular and widely used ICs in the electronics industry due to its simplicity, reliability, and versatility.

The IC555 is commonly used in various applications, including timing circuits, pulse generation, oscillators, PWM (Pulse Width Modulation) circuits, LED flashers, and many other electronic projects. It is available in different package types, such as DIP (Dual Inline Package) and SOIC (Small Outline Integrated Circuit).

Here are some key features and components of the IC555:

1. Voltage Supply: The IC555 operates on a wide range of voltage supplies, typically from 4.5V to 18V DC. It can work with both single-supply and dual-supply configurations.

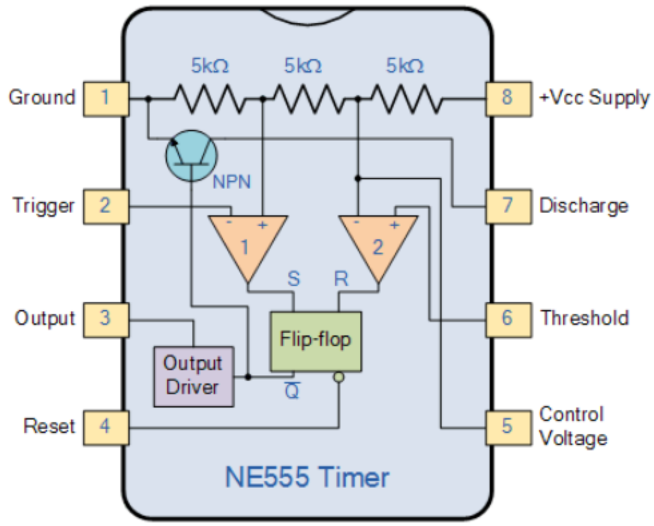

Figure 11: Integrated Circuit 555

2. Timing Capacitor (C1): The timing capacitor, connected to pins 2 and 6 (trigger and threshold), determines the timing characteristics of the IC555. By changing the value of the capacitor, you can adjust the timing intervals of the circuit.

3. Resistors: The IC555 uses external resistors to set various parameters, such as timing intervals and output pulse width. The most commonly used resistors are connected to pins 6 (threshold) and 7 (discharge).

4. Output (OUT): The output pin (pin 3) of the IC555 provides the desired output signal based on the circuit configuration. It can drive loads directly or can be used to trigger other components in the circuit.

5. Control Voltage (CV): The control voltage pin (pin 5) allows for external voltage control of the IC555. By applying a voltage to this pin, you can modulate the timing intervals or other parameters of the IC.

6. Trigger (TRIG) and Threshold (THR): These pins (pins 2 and 6) are used to control

the timing intervals of the IC555. By applying appropriate voltages to these pins, you can trigger or reset the timing circuit.

7. Discharge (DIS) and Reset (RST): These pins (pins 7 and 4) are used to discharge the timing capacitor or reset the IC, respectively. They are typically connected to the timing resistor or ground.

The IC555 can be configured in various modes, including astable mode (free-running oscillator), monostable mode (one-shot timer), and bistable mode (flip-flop). By changing the external component values and connections, you can achieve different timing characteristics and functionality.

The versatility and simplicity of the IC555 make it a popular choice for hobbyists, engineers, and students working on electronic projects. It is readily available and extensively documented, with numerous application notes and circuit examples available online and in electronics textbooks.

5.2.3 100k potentiometer with knob

A 100k resistance pot refers to a potentiometer (or variable resistor) with a resistance value of 100 kilohms (100,000 ohms). Potentiometers are commonly used in electronic circuits to vary the resistance in a controlled manner. They typically have three terminals: a fixed resistor element and two variable contacts (or wiper terminals). The resistance value can be adjusted by rotating the shaft or sliding the wiper.

The 100k resistance pot can be used in various applications, including volume control in

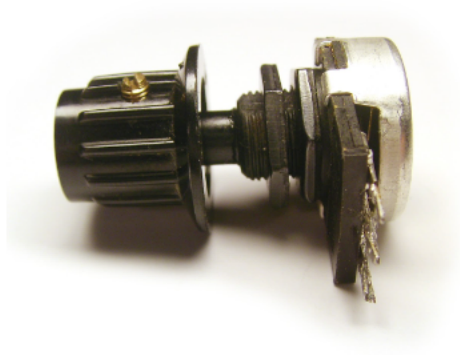

Figure 12: 100k potentiometer with knob

audio systems, brightness control in lighting circuits, or as a variable voltage divider in electronic circuits. The specific wiring and usage of the potentiometer will depend on the application and circuit requirements.

When using a 100k resistance pot or any other potentiometer, it's important to consider the power rating of the component to ensure it can handle the power dissipation in the circuit. Additionally, the tolerance of the potentiometer should be taken into account if precise resistance values are required.

If you have a specific question or need further information about using a 100k resistance pot in a particular application, please provide more details, and I'll be glad to assist you.

5.2.4 TIP122

The TIP122 is a popular NPN Darlington transistor that is commonly used for switching and amplification applications in electronic circuits. It is widely available and used in a variety of projects due to its robustness and high current-handling capabilities. Here are some key features and characteristics of the TIP122 transistor:

Figure 13: TIP122

1. Transistor Type: The TIP122 is an NPN (Negative-Positive-Negative) Darlington transistor, which means it consists of two internal NPN transistors connected in a Darlington configuration. This configuration provides high current gain and allows the transistor to handle high currents and voltages.

2. Collector-Base Voltage (Vcbo): The TIP122 has a maximum collector-base voltage rating of 100V. This means it can withstand a maximum voltage of 100V between the collector and the base terminals.

3. Collector-Emitter Voltage (Vceo): The maximum collector-emitter voltage rating of the TIP122 is 100V. This rating specifies the maximum voltage that can be applied across the collector and emitter terminals while the transistor is in active operation.

4. Collector Current (Ic): The TIP122 has a maximum collector current rating of 5A. This rating indicates the maximum continuous current that can flow through the collector terminal.

5. Base Current (Ib): The base current required to control the TIP122 depends on the desired collector current and the gain characteristics of the transistor. Generally, a base current of a few milliamperes is sufficient to drive the transistor into saturation.

6. Power Dissipation (Pd): The TIP122 has a maximum power dissipation rating of 65W. This rating indicates the maximum amount of power that the transistor can safely dissipate without exceeding its thermal limits.

7. Package Type: The TIP122 is typically available in a TO-220 package, which provides good thermal conductivity and easy mounting on heat sinks.

The TIP122 transistor is commonly used in applications such as relay drivers, motor controls, power-switching circuits, and general-purpose amplification. When using the TIP122 in a circuit, it is important to follow the datasheet specifications, consider the maximum ratings, and ensure proper heat dissipation to prevent overheating.

6 DC Power Supply

6.1 12 Volt 10 Ampere DC Power Supply

12 Volt 10 Ampere DC Power Supply A 12-volt, 10-ampere DC power supply is a device that can provide a constant direct current (DC) output with a voltage of 12 volts and a maximum current of 10 amperes. It is commonly used to power various electronic devices, such as routers, CCTV cameras, LED lights, and small appliances.

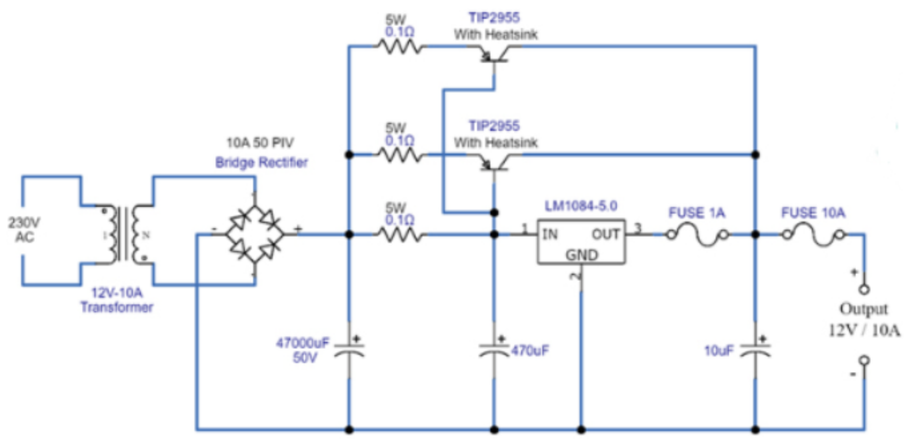

Figure 14: 12 Volt 10 Ampere DC Power Supply

The power supply typically consists of a transformer, rectifier, and voltage regulator circuitry. The transformer converts the input AC voltage to a lower level (usually around 12 volts). The rectifier converts the AC voltage to DC voltage, and the voltage regulator ensures that the output voltage remains stable at 12 volts, even with changes in the input voltage or load conditions.

When selecting a power supply, it's important to ensure that its specifications match the requirements of the device you intend to power. In this case, the power supply can provide a maximum of 10 amperes of current at a constant voltage of 12 volts.

It's also worth noting that when using a power supply, the device being powered should have a current draw within the power supply's rated capacity. Drawing more current than the power supply can provide may cause the power supply to overheat or fail.

Additionally, ensure that the power supply is equipped with appropriate safety features such as overload protection, short circuit protection, and overvoltage protection to safeguard both the power supply and the connected devices.

Table 1: 12 Volt 10 Ampere DC Power Supply Components

Components	**Value**	**Qty**
Voltage regulator IC	LM7812	1
Transistor	TIP2955	2
Transformer	230/12V 10A	1
Bridge Rectifier	10A 50 PIV	1
Resistor	0.1 Ohm 5W	3
Fuse	1A, 10A	1
Electrolyte Capacitor	10µF, 470µF, 47000µF	3
AC Supply	230V	1

6.1.1 Voltage Regulators

The function of a voltage regulator is to maintain a constant DC voltage at the output irrespective of voltage fluctuations at the input and (or) variations in the load current. In other words, voltage regulator produces a regulated DC output voltage. Voltage regulators are also available in Integrated Circuits (IC) forms. These are called as voltage regulator ICs.

There are two types of voltage regulators

1. Fixed voltage regulators

2. Adjustable voltage regulators

A fixed voltage regulator produces a fixed DC output voltage, which is either positive or

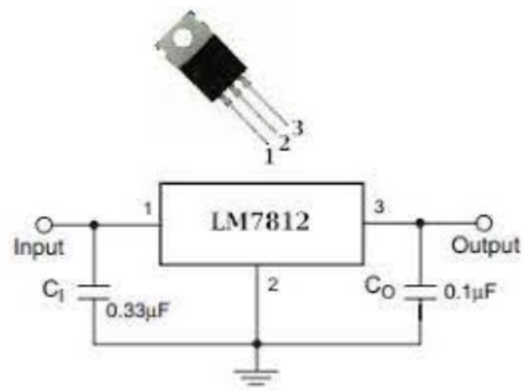

Figure 15: Voltage Regulators

negative. In other words, some fixed voltage regulators produce positive fixed DC voltage values, while others have negative fixed DC voltage values. 78xx voltage regulator ICs produce positive fixed DC voltage values, whereas, 79xx voltage regulator ICs produce negative fixed DC voltage values.

6.1.2 Transistor (TIP2955)

The TIP2955 is a popular power transistor used in a wide range of applications that require high power amplification or switching capabilities. It is an NPN bipolar junction transistor (BJT) designed for general-purpose power amplifiers and switching applications.

Here are some key specifications and features of the TIP2955 transistor:

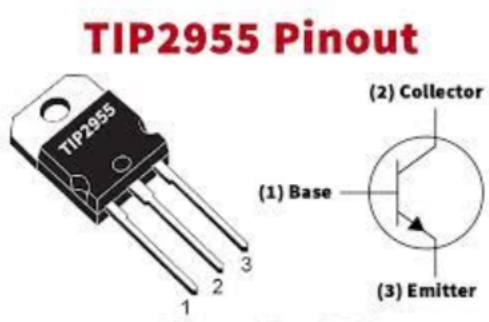

Figure 16: Transistor (TIP2955)

Maximum Collector Current (Ic): The TIP2955 can handle a maximum collector current of up to 15 amperes. This makes it suitable for applications that require high-current amplification or switching.

Collector-Emitter Voltage (Vce): The maximum voltage that can be applied between the collector and emitter of the TIP2955 is 60 volts. This voltage rating determines the maximum voltage the transistor can handle without breakdown.

Power Dissipation (Pd): The TIP2955 can dissipate a maximum power of 90 watts. This specification is important for determining the amount of heat the transistor can handle without exceeding its temperature limits. Adequate heat sinking may be required for high-power applications.

Gain (hFE): The TIP2955 has a typical DC current gain (hFE) of around 15 to 60. This parameter indicates the amplification capability of the transistor.

Package: The TIP2955 transistor is available in a TO-247 package, which provides good thermal dissipation properties and mechanical robustness.

Due to its high power handling capabilities, the TIP2955 transistor is commonly used in audio amplifiers, power supply circuits, motor control circuits, and other applications that require high current and voltage switching. It is important to consult the transistor's datasheet and application notes for specific circuit configurations and guidelines to ensure proper usage and performance.

6.1.3 220v to 12v 10a transformer

To convert 220 volts AC (alternating current) to 12 volts DC (direct current) at 10 amperes, you would need a transformer and a rectifier circuit. Here's a step-by-step overview of the process:

Transformer: Start with a step-down transformer that can convert the 220 volts AC input to a lower AC voltage suitable for rectification. In this case, you would need a transformer that steps down the voltage from 220 volts AC to around 12 volts AC.

Figure 17: 220v to 12v 10a transformer

Rectification: After the transformer, you'll need to rectify the AC voltage to DC using a

rectifier circuit. A common choice is a bridge rectifier, which consists of diodes arranged in a bridge configuration. The bridge rectifier converts the AC voltage to pulsating DC voltage.
Filtering: The pulsating DC output from the rectifier still contains ripples and fluctuations. To smooth out the voltage, a filter capacitor is used. The capacitor helps to reduce the ripples and provide a more stable DC output.
Regulation: If you require a precise and stable 12-volt output, you may need to add a voltage regulator circuit to ensure a constant voltage despite variations in the input voltage or load conditions. This circuit can be implemented using linear regulators or switching regulators depending on the specific requirements of your application.
It's important to note that the transformer and rectifier should be selected to handle the required current and power rating. In this case, a transformer capable of handling a current of at least 10 amperes should be chosen, along with diodes and a filter capacitor that can handle the same current.
If you're not familiar with designing and building power supply circuits, it's recommended to consult a qualified electrical engineer or use pre-made power supply modules that meet your specific requirements. This ensures proper functionality, efficiency, and safety in your power supply design.

6.1.4 Bridge Rectifier 10A 50 PIV

A bridge rectifier with a rating of 10A and a PIV (Peak Inverse Voltage) of 50V would be suitable for converting the AC voltage to DC in your application. Let's break down the specifications:

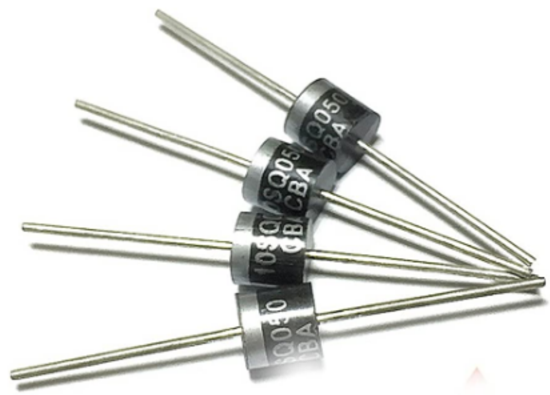

Figure 18: Bridge Rectifier 10A 50 PIV

Current Rating (10A): The bridge rectifier is capable of handling a maximum current of 10 amperes. This means it can handle a load of up to 10 amperes in your circuit without getting damaged or overheating. Ensure that the other components in your power supply, such as the transformer and filter capacitor, can also handle this current rating.

PIV (50V): PIV stands for Peak Inverse Voltage, which refers to the maximum voltage that the bridge rectifier can withstand in the reverse-biased direction. In this case, the bridge rectifier can handle a maximum reverse voltage of 50 volts. It is important to choose a PIV rating higher than the maximum expected voltage in your circuit to ensure reliable operation and prevent breakdown.

The bridge rectifier is a crucial component in the AC-to-DC conversion process, as it allows the current to flow in only one direction, effectively converting the AC voltage to pulsating DC. The specific bridge rectifier you mentioned is capable of handling currents up to 10 amperes and can withstand reverse voltages up to 50 volts.

When using a bridge rectifier, it is also recommended to consider the heat dissipation requirements. Depending on the power dissipated in the bridge rectifier due to the current flow, you may need to use a heat sink or ensure adequate ventilation to prevent overheating.

7 System Design and Control

7.1 System Design

7.1.1 RGB LED Module

A hemispherical luminaire refers to a lighting fixture or device that emits light in a hemispherical pattern. This means that the light emitted from the luminaire is directed at a 120-degree angle, covering a wide area horizontally but with limited vertical distribution.

Hemispherical luminaires are commonly used in applications where a broad, even distribution of light is required, such as outdoor area lighting, parking lots, sports fields, or large open spaces. They are designed to provide uniform illumination over a wide area, typically mounted on poles or structures at a suitable height to achieve the desired lighting coverage. These luminaires can come in various sizes, wattages, and light sources, including LED,

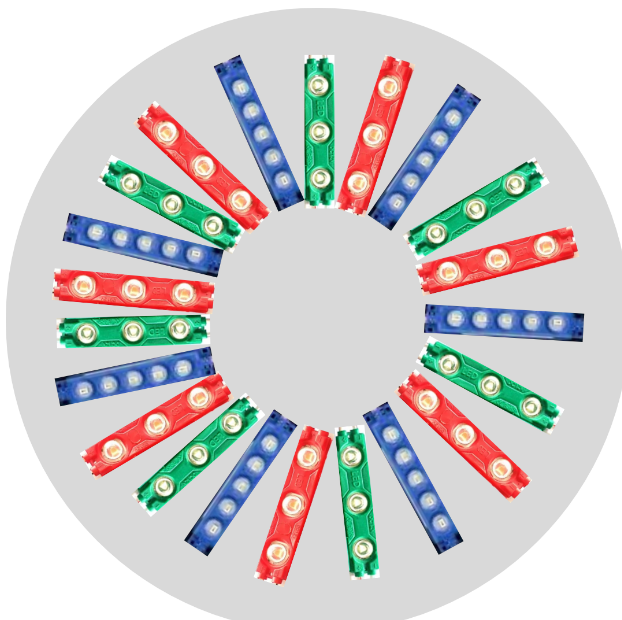

Figure 19: RGB LED Module

metal halide, or high-pressure sodium lamps.

LED-based hemispherical luminaires have gained popularity in recent years due to their energy efficiency, longer lifespan, and flexibility in controlling light output and color temperature.

It's worth noting that specific product offerings and features may vary across manufacturers, so it's always recommended to refer to the product specifications and consult with lighting professionals or suppliers for detailed information on a particular hemispherical luminaire.

The term "knee voltage" is commonly used to refer to the forward voltage drop across an LED when it starts to conduct current. For a red LED, the typical knee voltage is around 1.8 to 2.2 volts. The knee current for a red LED ranges from a few milliamperes (mA) up to 20 mA.

The knee voltage of a blue LED typically ranges from 2.7 to 3.7 volts. This means that the LED will start to conduct current and emit light when a forward voltage of around 2.7 to 3.7 volts is applied across it. The knee current for a blue LED is typically in the range of 5 to 20 milliamperes (mA). This means that the LED will start to emit visible light when the forward current reaches this range.

The knee voltage of a green LED typically ranges from 2.0 to 2.5 volts. This means that the LED will start to conduct current and emit light when a forward voltage of around 2.0 to 2.5 volts is applied across it. The knee current for a green LED is typically in the range of 5 to 20 milliamperes (mA). This means that the LED will start to emit visible light when the forward current reaches this range.

7.1.2 RGB Control

RGB dimming control using a PWM (Pulse Width Modulation) dimmer is a common method for adjusting the brightness of RGB (Red, Green, Blue) LED lights. PWM dimming involves rapidly turning the LED on and off at varying duty cycles to achieve different levels of brightness.

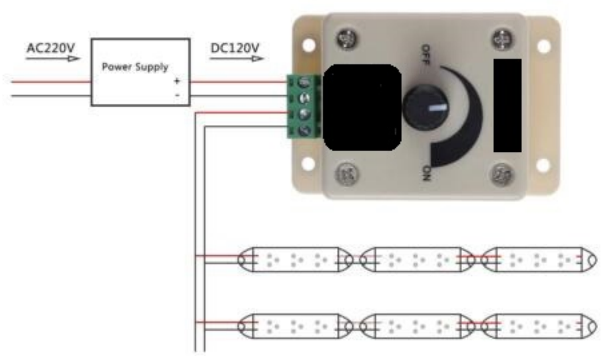

Figure 20: RGB dimming control using a PWM

Here's a general overview of how RGB dimming control with a PWM dimmer works:

RGB LED Configuration: The RGB LED module should consist of separate red, green, and blue LED elements or channels that can be individually controlled.

PWM Dimmer: You'll need a PWM dimmer capable of driving the RGB LED module. The dimmer should have multiple output channels, one for each color (red, green, blue). PWM dimmers can be analog or digital, and they generate variable-width pulses to control the

LED brightness.

Wiring: Connect the PWM dimmer outputs to the corresponding inputs of the RGB LED module. Typically, each color channel has a positive terminal (+) and a negative terminal (-). Ensure proper wiring and polarity to avoid damaging the LEDs.

Control Signals: The PWM dimmer requires control signals to adjust the brightness of each channel. These control signals can be provided by a microcontroller, a dedicated lighting controller, or manually using potentiometers or buttons connected to the dimmer.

PWM Signal Generation: The control signals for each channel determine the duty cycle of the PWM signals generated by the dimmer. A higher duty cycle means the LED is on for a longer duration, resulting in higher brightness, while a lower duty cycle reduces the brightness.

Color Mixing: By adjusting the duty cycles of the red, green, and blue channels independently, you can achieve different colors. For example, mixing red and green at high brightness and blue at low brightness will result in yellow light.

Dimming Range: The dimming range and resolution depend on the PWM frequency and the capabilities of the dimmer. Higher PWM frequencies generally provide smoother dimming, while lower frequencies may introduce visible flickering.

It's important to consult the documentation and specifications of your specific PWM dimmer and RGB LED module for detailed instructions and compatibility information. Additionally, using a microcontroller or lighting controller can provide more advanced control options, such as color transitions, patterns, and synchronization with other devices.

8 Measurement of Chromaticity of Light

8.1 Chromaticity-coordinates-of-white-light-in-the-CIE-1931-chromaticity-diagram

The chromaticity of light refers to its perceived color characteristics, independent of its intensity. It is often described using color coordinates that represent the hue and saturation of the light.

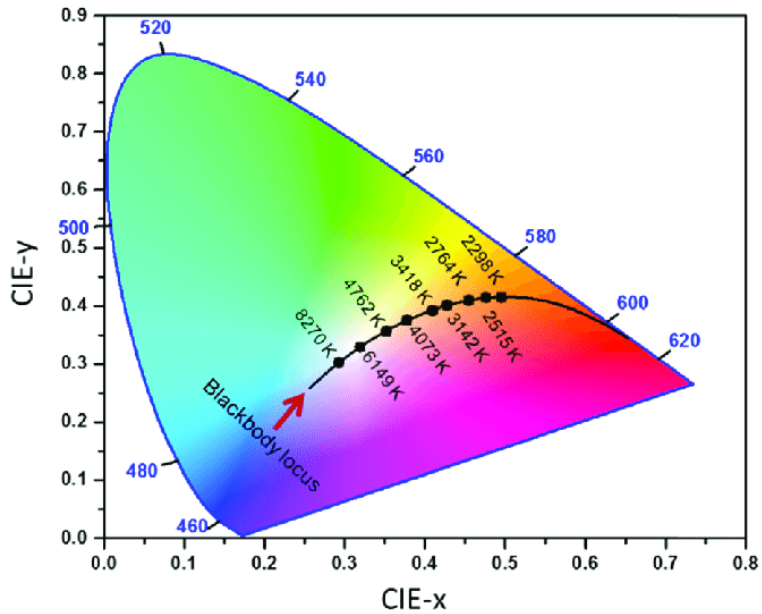

Figure 21: Chromaticity-coordinates-of-white-light-in-the-CIE-1931-chromaticity-diagram

In the field of color science, chromaticity is typically represented using the CIE 1931 xy color space or the CIE 1976 u'v' color space. These color spaces define the chromaticity values based on the response of the human visual system.

In the CIE 1931 xy color space, chromaticity is represented by two coordinates, x and y, which indicate the proportion of red, green, and blue light components in a particular light source. These coordinates range from 0 to 1, with the sum of x and y always equal to 1.

In the CIE 1976 u'v' color space, chromaticity is represented by u' and v' coordinates, which are derived from the CIE 1931 xy values. The u'v' coordinates are calculated to provide a more uniform color space.

By representing light in terms of chromaticity, it becomes possible to analyze and compare different light sources, classify colors, and understand their perceptual relationships. It is an essential concept in various fields such as lighting design, color reproduction, and colorimetry.

8.2 Chromameter

A chromameter is a device used to measure the chromaticity of an object or light source. It is commonly used in fields such as color science, quality control, and product development. A chromameter works by quantifying the color characteristics of an object or light source based on its spectral reflectance or transmittance properties. The device typically consists of a light source, a set of filters to isolate specific wavelengths or color channels, and a detector or sensor to measure the intensity of the reflected or transmitted light.

To measure the chromaticity of an object, the chromameter illuminates the object with a standardized light source and measures the reflected or transmitted light across different wavelengths or color channels. By comparing these measurements to known color standards or reference values, the chromameter can determine the chromaticity coordinates of the object, typically represented in color spaces such as CIE XYZ, CIE Lab, or CIE Luv.

Chromameters are used in various applications, including color matching and calibration, color quality control in manufacturing processes, evaluation of skin color for cosmetics and

Figure 22: Chromameter

dermatology, and assessment of color in artworks and textiles. They provide objective measurements of color, enabling precise analysis and comparison of different samples or light sources.

Chroma Meter CL-200A

Table 2: Chroma Meter CL-200A Specifications

Power source	2 AA-size batteries/AC adapter (optional)
Measuring function	Chromaticity, CCT, Tristimulus values
Cosine response(f2)	Ev: Within 3Percent
Receptor	Silicon photocell
Display	4 Significant-digit LCD with back-light illumination
Dimensions	69x174x35mm
Repeatability	Ev: 0.5Perc +1 digit(2) xy: ±0.0005
Temperature drift	Ev: ±3Perc ±1digit of displayed value, xy: ±0.003
Humidity drift	Ev: ±3Perc ±1digit of displayed value, xy: ±0.003

8.3 Plane to Test the chromaticity of the luminaire's (x,y) Coordinates

To test the (x, y) coordinates of the chromaticity of light emitted by a luminaire, you can follow these steps:

1. Prepare the setup: Set up a controlled environment where you can measure the light emitted by the luminaire without interference from other light sources. Ensure that the luminaire is properly installed and powered.

2. Select the measurement instrument: Choose a suitable device for measuring chromaticity coordinates, such as a spectroradiometer or a colorimeter. These instruments can accurately measure the spectral power distribution of light and calculate the corresponding chromaticity coordinates.

3. Calibrate the measurement instrument: Before taking measurements, it's essential to calibrate the measurement instrument according to the manufacturer's instructions. Calibration ensures accurate and reliable results.

4. Position the measurement plane: Place the measurement plane at a specific distance from the luminaire, taking into account the desired measurement parameters and standards. The measurement plane can be a flat surface or a specialized measurement target.

5. Measure the light: Point the measurement instrument towards the luminaire and take the light measurements. The instrument will capture the spectral distribution of the light emitted by the luminaire.

6. Calculate the chromaticity coordinates: Once you have obtained the spectral data, use appropriate software or algorithms to calculate the (x, y) chromaticity coordinates. These calculations are typically based on standardized color spaces like CIE 1931 xy or CIE 1976

u'v'.

7. Analyze the results: Examine the calculated chromaticity coordinates to assess the color characteristics of the light emitted by the luminaire. Compare the results to desired specifications or industry standards to determine if the luminaire meets the required chromaticity requirements.

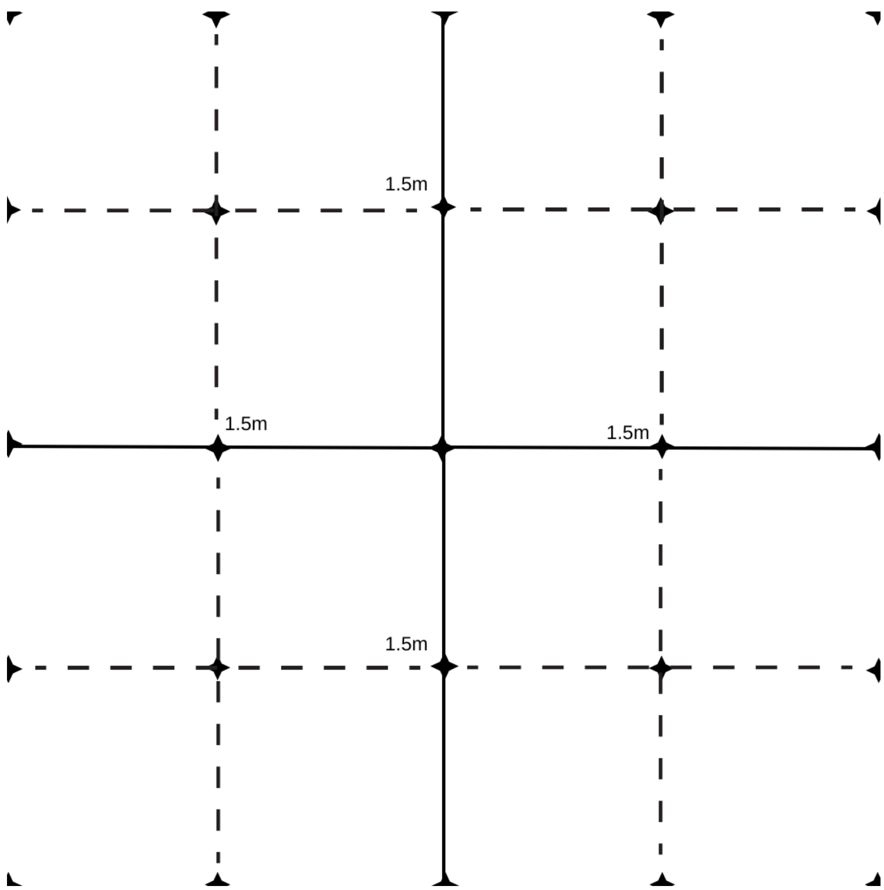

Figure 23: Plane to Test the luminaire (x,y) Coordinates

8.4 Measurement of chromaticity (x,y) Coordinate

Reading for Blue

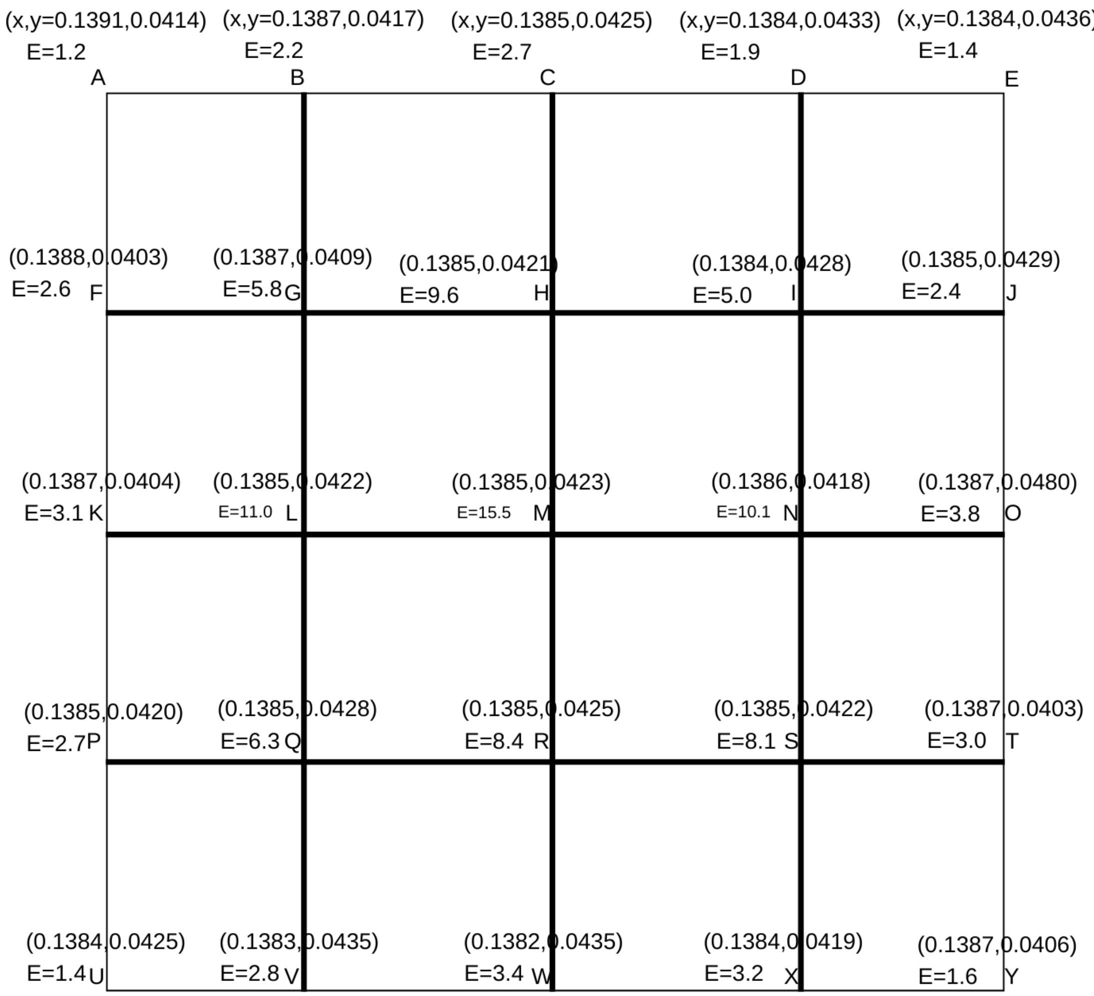

Figure 24: Measurement of chromaticity (x,y) Coordinate for BLUE.

Reading for Red

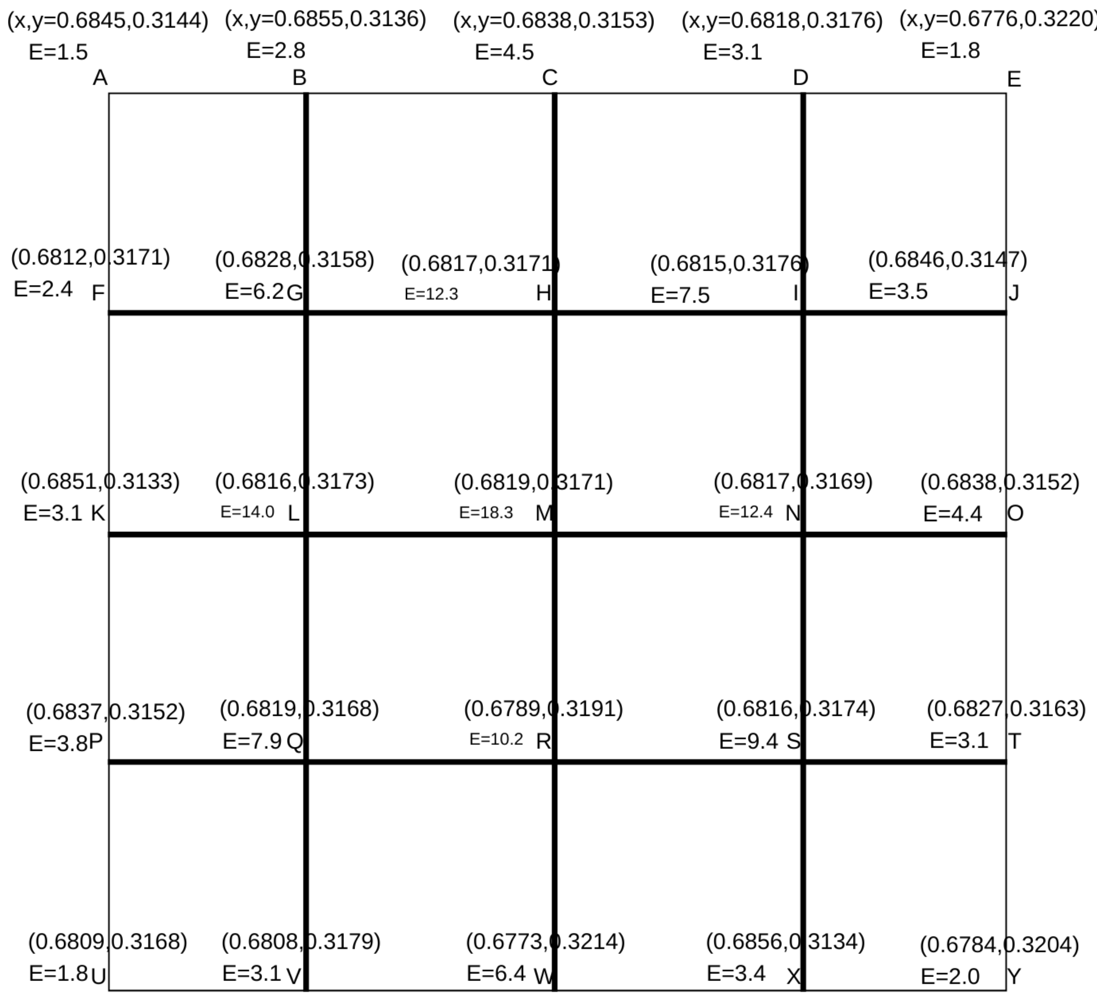

Figure 25: Measurement of chromaticity (x,y) Coordinate for RED

Reading for Green

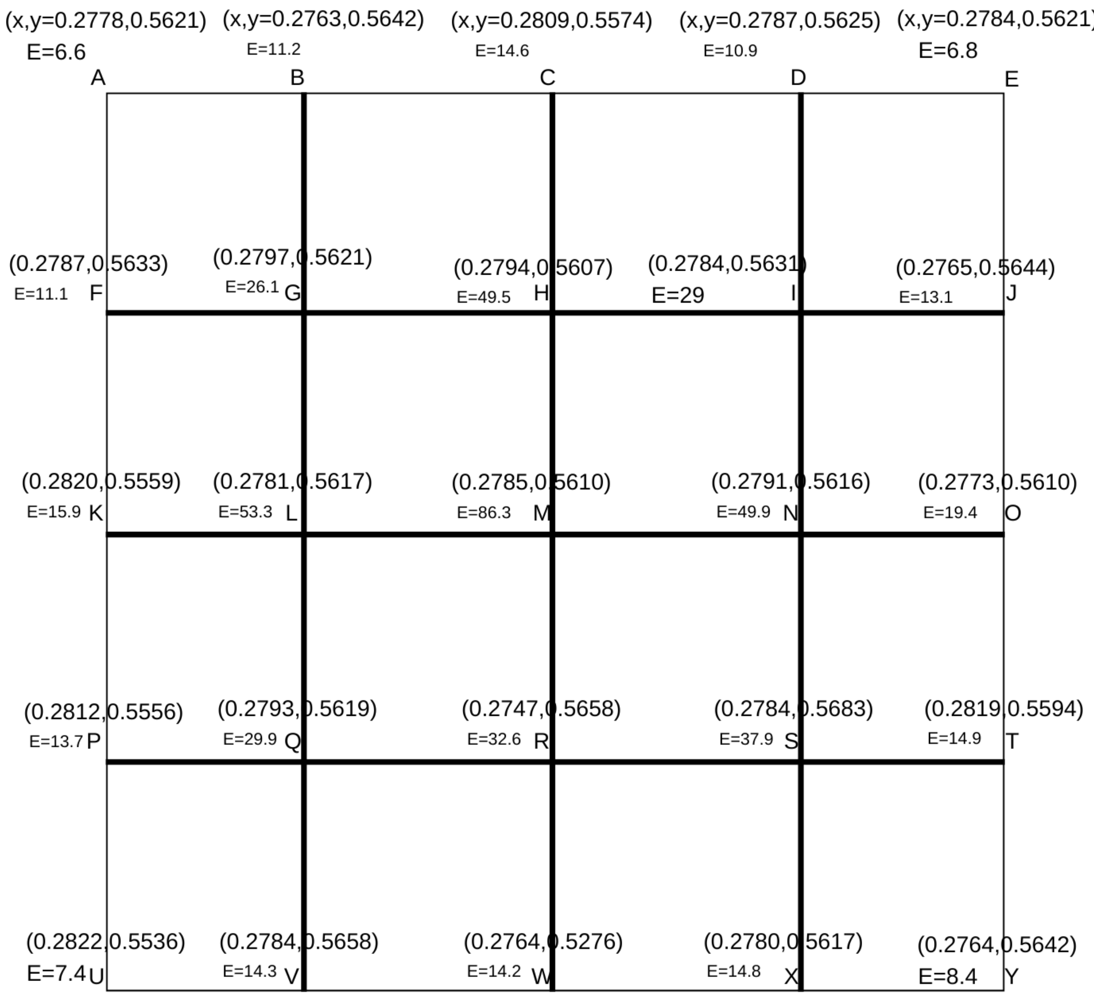

Figure 26: Measurement of chromaticity (x,y) Coordinate for GREEN

8.5 Measurement and Calculation of Average illuminance and Uniformity

8.5.1 Average illuminance

Average illuminance refers to the average amount of light falling on a surface within a specific area. It is a measure of the overall brightness or luminous flux density in that area.

Illuminance is typically measured in lux (lx), which represents the amount of light (luminous flux) per unit area (square meter). To calculate the average illuminance, you would need to measure the illuminance at multiple points within the area of interest and then average those measurements.

Here's a step-by-step process to calculate the average illuminance:

Select the area of interest: Determine the specific area for which you want to calculate the average illuminance. It could be a room, a workspace, or any defined region. Measure illuminance at multiple points: Use a lux meter or an illuminance meter to measure the illuminance at several points within the selected area. Take measurements at representative locations to ensure a comprehensive representation of the light levels. Record the measurements: Note down the illuminance values obtained at each measurement point. Calculate the average illuminance: Add up all the measured illuminance values and divide the sum by the total number of measurements taken. The result will be the average illuminance for the area.

Average illuminance provides a useful metric for assessing the general lighting conditions in an area. It is commonly used in lighting design, architecture, and various applications where the level of illumination is important for visual comfort, safety, or productivity.

8.5.2 Uniformity

The uniformity of a luminaire refers to how evenly it distributes light across a given area. It is a measure of the consistency of illumination across that area.uniformity is typically expressed as a ratio or percentage, comparing the illuminance or luminance at different points within the illuminated space. The higher the uniformity value, the more evenly the luminaire distributes light.

To evaluate the uniformity of a luminaire, you can follow these steps:

1. Define the evaluation area: Determine the specific area or surface where you want to assess the uniformity of illumination. It could be a floor, a workspace, a wall, or any other defined region.

2. Measure illuminance or luminance: Use an appropriate measuring device, such as a lux meter or a luminance meter, to take measurements at multiple points within the evaluation area. Record the illuminance or luminance values obtained at each point.

3. Determine the minimum and maximum values: Identify the lowest illuminance or luminance measurement (usually at a point farthest from the luminaire) and the highest measurement (typically at a point closest to the luminaire) within the evaluation area.

4. Calculate the uniformity ratio or percentage: Divide the minimum illuminance or luminance value by the maximum value, then multiply the result by 100 to obtain uniformity as a percentage. Alternatively, you can express the uniformity as a ratio, by dividing the minimum value by the maximum value.

A higher uniformity value (closer to 100 or a ratio close to 1) indicates more even distribution of light, resulting in a more uniform lighting environment. On the other hand, a lower uniformity value (further from 100 or a ratio farther from 1) suggests a more significant variation in light levels, leading to a less uniform lighting condition. Assessing the uniformity of a luminaire helps in determining if the lighting system adequately illuminates the desired area without significant variations or hotspots. It is particularly important in applications where visual comfort, safety, and task performance are crucial factors.

8.5.3 Average illuminance, Uniformity and Chromaticity (x,y) Values

Quadrant-2	
Xb= 0.1386	Yb= 0.0415
Xr= 0.6831	Yr= 0.3156
Xg= 0.2790	Yg= 0.5609
Eb= 5.96Lux	Ub= 0.201
Er= 7.23Lux	Ur= 0.207
Eg= 30.5Lux	Ug=0.216

Quadrant-1	
Xb= 0.1386	Yb= 0.0415
Xr= 0.6831	Yr= 0.3156
Xg= 0.2790	Yg= 0.5609
Eb= 5.96Lux	Ub= 0.201
Er= 7.23Lux	Ur= 0.207
Eg= 30.5Lux	Ug=0.216

Quadrant-3	
Xb= 0.1384	Yb= 0.0423
Xr= 0.6814	Yr= 0.3172
Xg= 0.2789	Yg= 0.5609
Eb= 6.66Lux	Ub= 0.21
Er= 7.62Lux	Ur= 0.23
Eg= 29.7Lux	Ug=0.24

Quadrant-4	
Xb= 0.1385	Yb= 0.0425
Xr= 0.6820	Yr= 0.3174
Xg= 0.2778	Yg= 0.5629
Eb= 6.34Lux	Ub= 0.25
Er= 7.73Lux	Ur= 0.25
Eg= 30.9Lux	Ug=0.27

Figure 27: Measured and Calculated values

9 Colour mixing of RED BLUE GREEN LED

When it comes to color mixing using RGB LEDs, We can combine different intensities of red (R), green (G), and blue (B) light to create a wide range of colors. By adjusting the brightness of each individual LED, you can achieve various shades and hues.
Here's a brief overview of how color mixing works with RGB LEDs:
1. Red (R) LED: When the red LED is at its maximum intensity (full brightness), it emits pure red light. As you decrease the intensity, the color becomes darker until the LED is completely off.
2. Green (G) LED: Similarly, the green LED emits pure green light at maximum intensity and becomes darker as the intensity decreases.
3. Blue (B) LED: The blue LED emits pure blue light at maximum intensity and gets darker as the intensity is reduced.

Results of Colour Mixing

Table 3: Results of Colour Mixing

CCT	RED	GREEN	BLUE
7851	12.5 Percent	12.5 Percent	12.5 Percent
11680	25 Percent	25 Percent	25 Percent
12830	37.5 Percent	37.5 Percent	37.5 Percent
19400	100 Percent	100 Percent	50 Percent

Conclusion

In conclusion, "DEVELOPMENT OF A RGB LED BASED SPECTRAL TUNABLE LIGHT SOURCE FOR IN-HOUSE PLANTATION" offers several advantages and possibilities for indoor plant cultivation. The RGB LED technology allows for precise control over the light spectrum, which is crucial for the growth and development of plants. By independently adjusting the intensity of red, green, and blue light, it becomes possible to tailor the lighting conditions to meet the specific needs of different plant species at various stages of growth.

This tunability allows for the optimization of light output, promoting photosynthesis, chlorophyll synthesis, and flowering in plants. It also enables the creation of dynamic lighting environments that mimic natural sunlight variations, promoting healthier and more robust growth. The ability to adjust the light spectrum can also be used to manipulate plant characteristics, such as altering leaf morphology or enhancing specific traits.

Furthermore, the use of RGB LED technology in indoor plant cultivation offers energy efficiency and longevity compared to traditional lighting sources. LEDs consume less power, generate less heat, and have longer lifespans, reducing energy costs and the need for frequent bulb replacements.

In-house plantation systems utilizing RGB LED-based light sources can be designed to be compact, customizable, and easily integrated into various indoor environments. They can be controlled and automated using smart systems, allowing for precise scheduling and adjustment of light settings based on plant requirements.

However, it is important to note that successful implementation of RGB LED-based light sources for in-house plantation requires careful consideration of factors such as plant species, growth stages, light intensity, and photoperiod. Adequate research, experimentation, and monitoring are necessary to optimize the lighting conditions for specific plants and achieve desired outcomes.

In summary, the development of an RGB LED-based separately tunable light source for in-house plantation offers great potential for efficient, effective, and customizable indoor plant cultivation. It enables precise control over light spectra, energy efficiency, and the creation of tailored lighting environments, contributing to healthier and more productive plant growth.

Future Scope

The development of an ”RGB LED-based spectral tunable light source for in-house plantation” holds significant future potential and opens up several areas for further exploration and advancement. Some of the future scopes in this field include:

1. Advanced Spectral Control: Enhancing the spectral control capabilities of RGB LED systems can lead to more precise manipulation of specific wavelengths or narrow bands of light. This can be achieved by incorporating additional LED colors or utilizing advanced control algorithms to fine-tune the output spectra. The ability to customize the light spectrum with higher resolution can further optimize plant growth, development, and specific biochemical processes.

2. Integration of Smart Technologies: Integrating RGB LED-based light sources with smart technologies and automation systems can revolutionize in-house plantation. By utilizing sensors, data analysis, and machine learning algorithms, it becomes possible to create dynamic lighting schedules and adapt lighting conditions in real-time based on plant responses, environmental factors, and growth stages. Smart systems can also facilitate remote monitoring and control of lighting parameters, improving efficiency and convenience.

3. Research on Plant Responses: Further research is needed to deepen our understanding of plant responses to different light spectra. Investigating the effects of specific wavelengths or combinations of light on specific plant species, growth stages, and desired traits can help optimize spectral tuning strategies. Understanding the underlying physiological and biochemical mechanisms can enable the development of tailored lighting approaches for various plants and applications.

4. Energy Efficiency and Sustainability: Ongoing research and development efforts should focus on improving the energy efficiency of RGB LED-based systems. This includes optimizing LED efficiency, minimizing energy losses in the driver circuitry, and exploring alternative energy sources for powering the lighting systems. Additionally, exploring sustainable materials and manufacturing processes for LED production can contribute to environmentally friendly practices.

5. Integration with Indoor Farming Systems: RGB LED-based light sources

can be integrated with other indoor farming technologies such as hydroponics, aeroponics, or vertical farming systems. Investigating the synergistic effects of combining advanced lighting with controlled environment agriculture techniques can lead to more efficient and productive indoor farming solutions.
6. Commercial Applications: As the technology advances and becomes more accessible, there is a growing market for RGB LED-based spectral tunable light sources in horticulture and indoor farming. Future developments may focus on scaling up production, reducing costs, and designing user-friendly systems that can be easily deployed in various indoor farming settings.
Overall, the future scope for RGB LED-based spectral tunable light sources in in-house plantation lies in advancing spectral control capabilities, integrating smart technologies, conducting in-depth plant response research, improving energy efficiency, exploring integration with other indoor farming systems, and expanding commercial applications. Continued innovation and collaboration among researchers, technologists, and horticulturists will pave the way for further advancements in this field.

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