“DESIGN & DEVELOPMENT OF DAYLIGHT-LIKE HIGH COLOR QUALITY LED LIGHT SOURCE FOR CRITICAL TASK PERFORMANCE”

A THESIS
SUBMITTED IN PERTIAL FULFILLMENT OF
THE REQUIREMENTS FOR DEGREE OF
MASTER OF ENGINEERING
IN
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Submitted by
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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "**DESIGN AND DEVELOPMENT OF DAYLIGHT-LIKE HIGH COLOR QUALITY LED LIGHT SOURCE FOR CRITICAL TASK PERFORMANCE"**, submitted by KAFIUR RAHMAN (Examination Roll no. **M4ILN23004 & Registration No. 160186 OF 2021-22**) under our supervision be accepted in partial fulfilment of the requirement for the degree of Master of Illumination Engineering.

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CERTIFICATE OF APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a satisfactory manner to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned do not necessarily endorse or approve any statement made, opinion expressed and conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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Declaration of Originality and Compliance of Academic Ethics

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

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 the rules and regulations, I have fully cited and referenced all material and results that are not original to my work.

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Abstract

This thesis focuses on the design and development of a high Color quality LED light source optimized for critical task performance, achieved by combining warm white, cool white, green, and blue LEDs. The primary objective is to create a daylight-like illumination with high Color Rendering Capability and ensuring superior color accuracy

The research begins with an in-depth analysis of the principles of human visual perception and the impact of lighting on task performance, emphasizing the need for high color quality light sources in critical applications. It investigates the spectral characteristics of warm white, cool white, green(527 nm) and blue(467 nm) LEDs to identify their individual strengths and limitations in achieving daylight-like illumination.

Additionally, the LED driver design is a critical component of the system, ensuring precise control of each LED's intensity and color balance. The driver is tailored to provide flicker-free, dimmable, and efficient operation while maintaining the desired color quality. Throughout the research, comprehensive testing and evaluation are conducted to validate the performance of the LED light source. Measurements of CRI, R9, luminance, and spectral distribution are taken under various operating conditions and compared to established standards. The results demonstrate the successful achievement of CRI values above 95 and R9 values exceeding 94, confirming the high color quality of the developed LED light source.

This thesis extends its investigation into the practical application of the designed and developed high color quality LED light source in a real-world setting—the morgue of NRS Medical College and Hospital. The case study explores the benefits and implications of implementing this innovative lighting solution in a critical environment where accurate color rendering and visual clarity are of utmost importance.

- ## Overview of the Thesis

  - **Chapter 1** Provides the Introduction of the system
  - **Chapter 2** Discusses about the Color Quality Metrics
  - **Chapter 3** Provides the information of different types of LEDs and LED Technologies
  - **Chapter 4** Describe the LED Driver Theory
  - **Chapter 5** Discusses the Literature Review
  - **Chapter 6 Present** the Mathematical Formulation of Color mixing as per Grassmann's Law of color mixing
  - **Chapter 7** Describe the Instruments Used for designing the light source and system implementation
  - **Chapter 8** Provides the Effective Lighting Design Calculation Method
  - **Chapter 9** Implementation of the Proposed System along with the circuit diagram
  - **Chapter 10** Full description of Evaluation and Testing in Laboratory
  - **Chapter 10** Details of A Case Study in Dialux and also in Practice.
  - **Chapter 12** Deals with Conclusions and future scope.
  - **References**
  - **Appendix**

Contents

CHAPTER-1 INTRODUCTION

High color quality LED light source is defined as the light source designed by using LEDs of different colors (white,green,blue) which has a continuous spectrum (SPD), the highest possible value of CRI (CRI>96) and proper CCT (5000K-6500K) as like the Daylight produce.But in practice only CCT(Kelvin) and CRI(Ra) does not decide the color quality of light it also requires some other parameters like **Extended CRI(R9-R15)**, **Duv.**Because for the critical tasks environments each color is very much important as in case of medical sectors the Red color and yellow color play a vital role and other colors may have great impact on the critical tasks which are being performed.

1.1 Background:

In the modern world, human tasks and activities have become increasingly demanding and require high levels of concentration, accuracy, and performance. One of the crucial factors that significantly influences human performance in various tasks is lighting. Adequate lighting is essential for visual clarity, comfort, and overall well-being. It has been thoroughly investigated how lighting affects human physiology and behavior and researchers have continuously emphasized the substantial effects of light on cognitive function, alertness, mood, and productivity.

Due to its several inherent advantages it offers as the balanced spectral composition and dynamic qualities, Natural daylight has been recognised as the optimal and ultimate lighting condition among all other light sources that has been designed artificially for the critical tasks. Some of the Advantages of Daylight for critical task performance are given below:

i. **Balanced and full Spectrum:**

Daylight provides a wide range of balanced full spectrum of colors covering the entire visible range, This full spectrum allows our eyes to perceive colors accurately and in their truest form. When working on critical tasks that require precise color discrimination, such as graphic design, medical procedures, or fine art, natural daylight ensures optimal visual acuity and reduces the likelihood of errors.

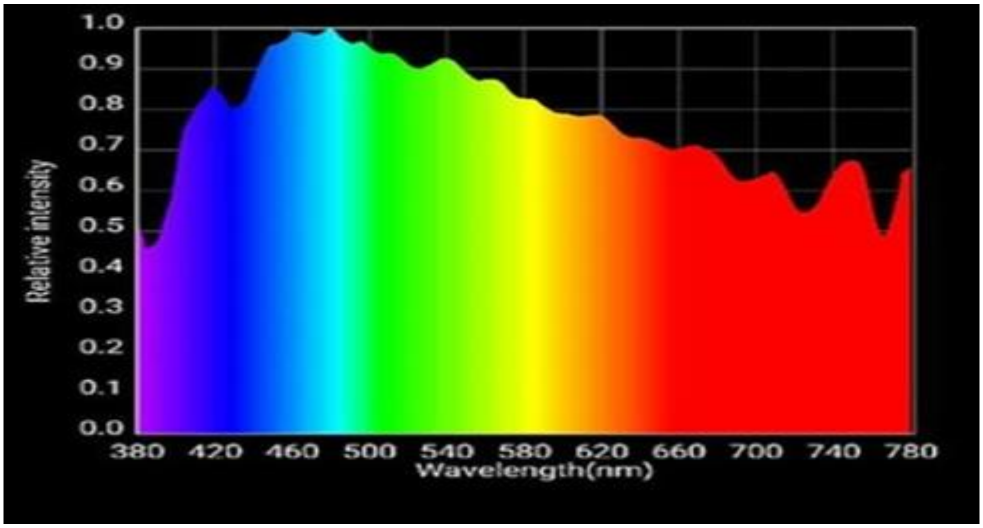


Fig.1 Spectrum of Daylight

ii. High Color Rendering Index (CRI) :

The CRI is a metric that quantifies a light source's ability to render colors accurately compared to natural daylight. Daylight has a CRI of 100, which is the highest possible value. This means that objects illuminated by daylight appear very close to how they would look under natural sunlight. High CRI is crucial for tasks that involve color evaluation and matching, as it ensures that critical details are not overlooked.

iii. Reduced Eye Strain and Fatigue :

Natural daylight provides a comfortable and diffused light that minimizes eye strain and fatigue compared to harsh artificial lighting. This is particularly important for tasks that require prolonged concentration, as reduced eye strain leads to increased comfort and sustained performance.

Due to these advantages, daylight offers the most favorable conditions for critical task performance, as it optimizes visual clarity, color perception, and cognitive function. However, relying solely on natural daylight is often impractical or impossible, especially in enclosed spaces or during nighttime hours. As a result, artificial light sources, such as incandescent bulbs and fluorescent lamps, have become more common. While these light sources offer convenience and versatility, they not only fail in providing a spectrum, CCT of natural daylight but also it consumes a lot of Electrical Power and also produces too much heat. Their constrained spectrum outputs and color quality capabilities could result in unsatisfactory task performance in the long term, as well as possible negative health effects.

To reduce the electrical power consumption we are compelled to think of the LEDs. The LEDs which are available in the market consumes very low amount of power but it cannot produce the Daylight like spectrum and also fails to give the proper CCT and also have very low Color Rendering Index(CRI) that is more than 80 in a nutshell the LEDs which are in the market have very low color quality.

To improve the Color quality of LEDs we are mixing the light of different colors (warm white, Cool white, Green and Blue) in specific ratios which are easily available in the market.

1.2 Problem Statement:

This thesis addresses the issue that current artificial light sources are unable to adequately mimic the benefits of natural daylight on the performance of crucial tasks. Artificial lighting solutions have been created to address a variety of illumination requirements, but they frequently fall short of offering the ideal lighting conditions needed for tasks that call for high levels of focus, accuracy, and visual acuity.

The main issues with conventional artificial light sources are as follows:

i. **Limited Color Rendering Capabilities:**

   All the artificial light sources have a restricted color rendering index (CRI), which indicates their ability to accurately render colors compared to natural daylight.The CRI of the light source that is easily available in the market is more than 85 (maximum) A lower CRI value means that colors may appear distorted or less vibrant, leading to potential errors in tasks that involve color matching, quality control, or design. In critical professions such as healthcare, where accurate color perception is essential for diagnosing medical conditions or distinguishing subtle tissue variations, the limitations of artificial light sources can have serious consequences.

ii. **Narrow Spectral Output:**

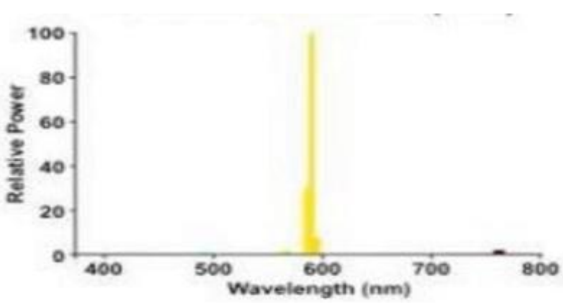
   Conventional artificial light sources frequently produce a narrow range of wavelengths, focussing on specific wavelengths excluding others that are present in natural daylight. This narrow spectral distribution can negatively impact visual perception and cognitive function.. Certain wavelengths of light, particularly blue light, have been shown to play a crucial role in enhancing alertness, focus, and overall cognitive performance. Artificial light sources without these desirable spectral components can fail to provide the right challenge to improve the critical task performance, particularly in circumstances when sustained focus and mental sharpness are crucial.

iii. **Inadequate Correlated Color Temperature (CCT):**

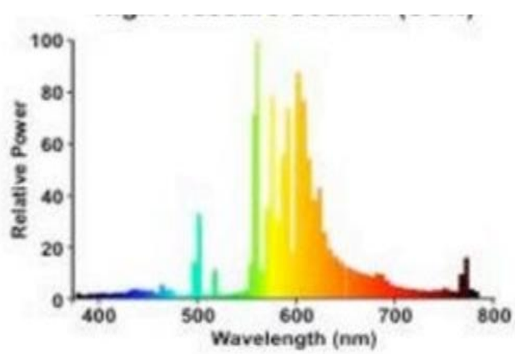
The correlated color temperature of a light source defines its perceived "warmth" or "coolness." Daylight is typically considered to have a neutral or cool appearance, with a color temperature ranging from 5000K to 6500K. This CCT range has been associated with increased visual acuity and attentiveness.

Unfortunately all the artificial light sources that are available in the market have fixed CCTs and that do not match the CCT range (5000K-6500K) of daylight throughout the day. More specifically, during certain times of the day when a special sensitive task or particular cognitive functions are more important, the inability to produce the CCT of artificial lighting which mimics the color temperature(CCT) range of daylight can prevent the achievement of optimal task performance and will give faulty result which has an adverse effect on professional level as well as in the society.

Addressing these limitations and designing a daylight-like high color quality light source has the potential to significantly enhance critical task performance and overall well-being in professional environments.



SPD Of Low Pressure Sodium



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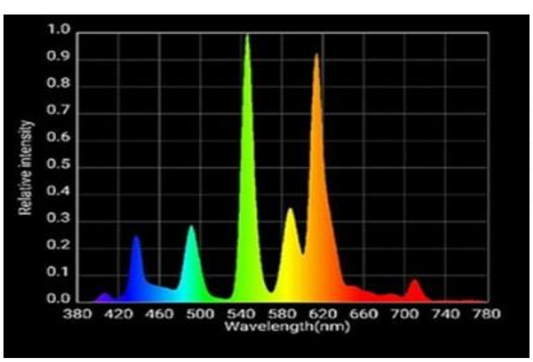
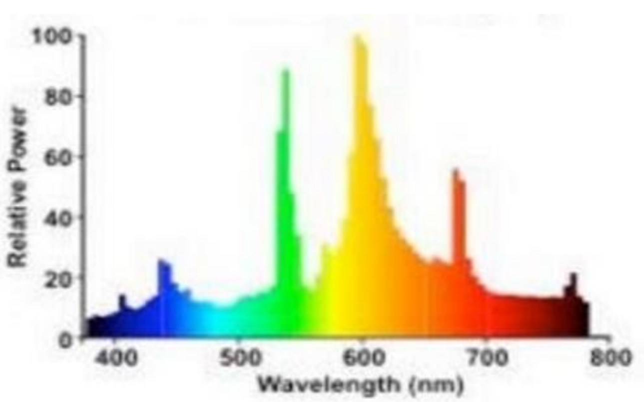
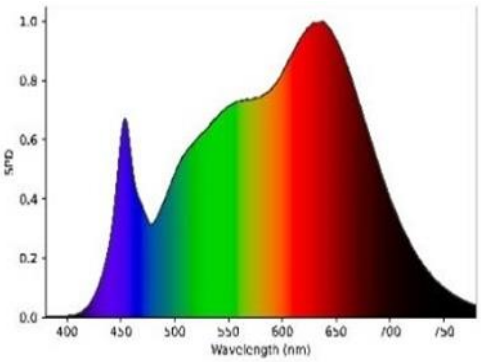
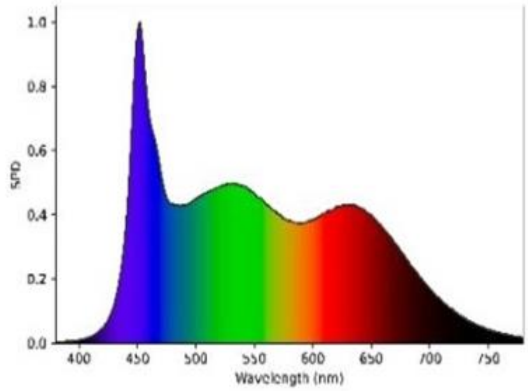


SPD Of Fluorescent



SPD Of Metal Halide





SPD OF Warm White LED SPD Of Cool White LED

1.3 Objectives:

The Primary Objectives The primary objectives of this research are as follows:

- To explore the impact of lighting on human performance in critical tasks and the importance of replicating daylight-like spectral properties in artificial light sources.
- To design and develop a high color quality light source that closely emulates the spectral characteristics of natural daylight, with particular attention to color rendering and correlated color temperature (CCT).
- To assess the performance of the daylight-like light source in critical task environments and compare it with existing artificial light sources in terms of cognitive function, visual acuity, and overall user satisfaction.

By meeting these goals, the thesis hopes to give valuable contributions to the development and manufacturing of a daylight-like high color quality light source that enhances performance on crucial tasks and this will potentially provide users with additional health and wellbeing benefits. The findings of the research can have a big impact on a variety of industries and environments where success depends on the ability to do tasks with accuracy, focus, and endurance.

1.4 Study and Scope:

The primary focus of this study is to create an artificial light source that replicates the spectral characteristics of natural daylight as closely as possible.The research will involve selecting appropriate lighting technologies and materials to achieve the desired spectral power distribution (SPD) which provides a balanced distribution of wavelengths, including blue light. Proper spectral optimization is critical to achieving a daylight-like lighting experience.The spectral optimization process will aim to include a balanced distribution of colors.To ensure high color quality, the developed light source will undergo precise evaluation for color rendering using metrics like the Color Rendering Index (CRI). The light source's correlated color temperature (CCT) will also be carefully matched with the daylight.The study will use a combination of laboratory experiments, controlled trials, and user feedback surveys to collect data and draw meaningful conclusions regarding the efficacy of the daylight-like light source for critical task performance. The goal is to create an adaptive light source that can mimic the natural daylight color temperature and color rendering capability.The study will emphasize the relevance and applicability of the daylight-like light source in various professional settings, such as offices, educational institutions, healthcare facilities, and industrial workspaces. Understanding the potential benefits of such lighting solutions in these environments will provide valuable insights for optimizing productivity and well-being in the workforce.It is essential to acknowledge the limitations of this study. While efforts will be made to design the daylight-like light source to mimic natural daylight as closely as possible, it may not fully replicate all the dynamic properties of sunlight. Moreover, the scope of the study will not extend to large-scale implementation and long-term health effects and human centric lighting parameters ,which would require further research beyond the scope of this thesis.Here we have compromised a little amount of CCT value to get high CRI as well as R9 value.If we can mix the green,blue,cool white and warm white in proper ratio then maybe we don't have to compromise the CCT.

1.5 Research Methodology:

To achieve the objectives of designing and developing a daylight-like high color quality light source and assessing its impact on critical task performance, a rigorous and comprehensive research methodology has been employed.

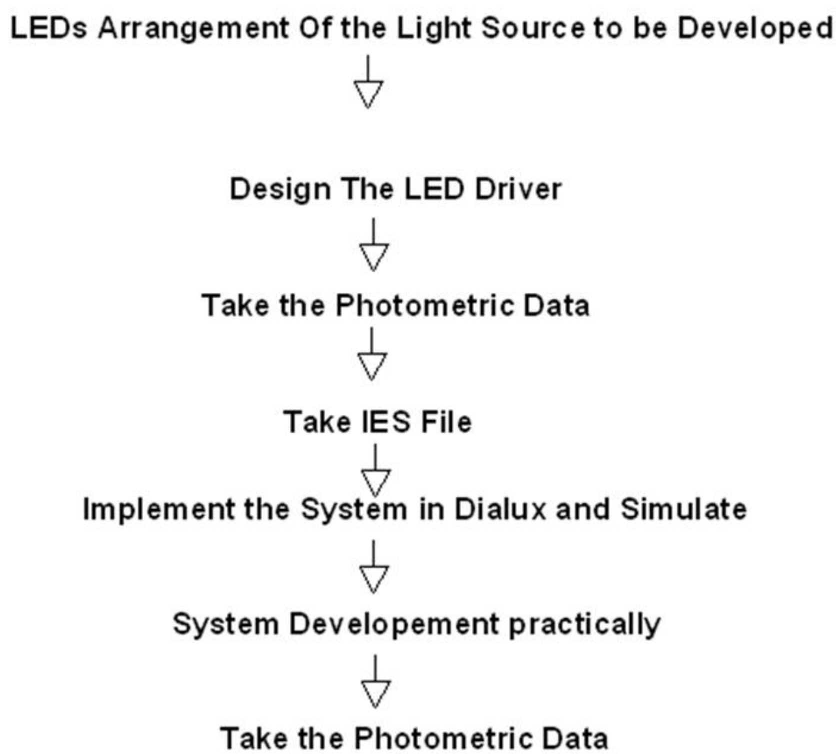
To get the continuous Spectrum, proper CCT and high CRI we have mixed Four colors of LEDs (Warm White, Cool White, Green and Blue) which are available in the market.

We have taken the Photometric and Colorimetric data of the developed light source for several times.If some changes were required then no of LEDs may be of any color has been changed and sometimes the current level of the required color has also been changed according to the requirement(High CRI, proper CCT, Deviation from planckian Locus). After getting the data we analyzed them and compared all the parameters and finally selected the product to be ready.

After taking the photometric data (IES File) we have artificially designed and developed a system where the critical tasks can be performed, we have used the designed light source and got the proper results in Dialux.

We have also Implemented the proposed system and got the proper data whatever is required for the critical tasks and taken the feedback from the user.

The research findings will contribute to the understanding of the role of lighting in human performance and may have implications for various professional environments where task performance is critical.



FLOWCHART OF THE METHODOLOGY

CHAPTER-2 COLOR QUALITY METRICS

Color quality metrics are objective measures used to assess the accuracy, consistency, and overall quality of colors produced or reproduced by various light sources, systems, or processes. These metrics help quantify how well colors match a reference standard (Daylight) and provide a standardized way to evaluate color performance. There are several color quality metrics commonly used in the field of color science and technology.

2.1 Color Rendering Index(CRI) :

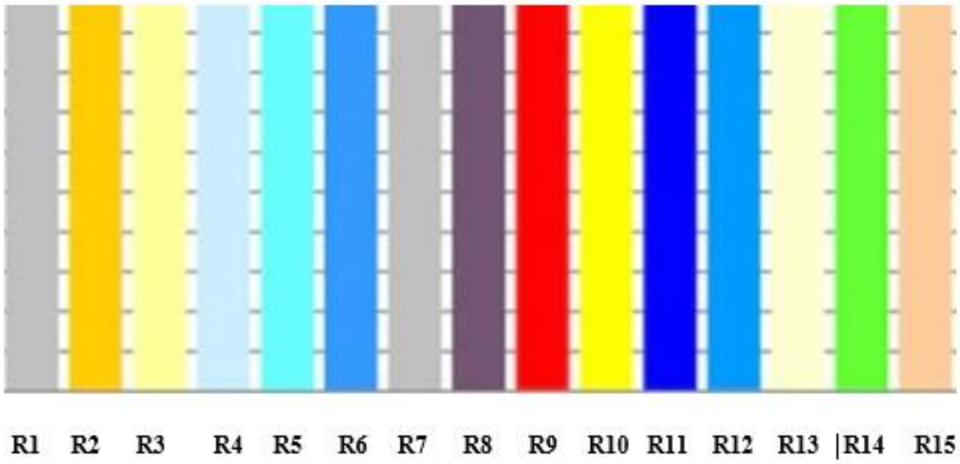
A color rendering index (CRI) is a quantitative measure of the ability of a light source to reveal the colors of various objects faithfully in comparison with a natural or standard light source. Light sources with a high CRI are desirable in color-critical applications such as neonatal care (new born baby),Morgue and art restoration.(protection and care of cultural properties, archeology, museum).

Color rendering, as defined by the International Commission on Illumination (CIE), is the effect of an illuminant on the color appearance of objects by conscious or subconscious in comparison with their color appearance under a reference or standard illuminant.

The CRI of a light source does not indicate the apparent color of the light source; that information is given by the correlated color temperature (CCT). The CRI is determined by the light source's spectrum. An incandescent lamp has a continuous spectrum, a fluorescent lamp has a discrete line spectrum; implying that the incandescent lamp has the higher CRI.

The value often quoted as "CRI" on commercially available lighting products is properly called the CIE Ra value, "CRI" being a general term and CIE Ra being the international standard color rendering index.

Numerically, the highest possible CIE Ra value is 100 and would only be given to a source whose spectrum is identical to the spectrum of daylight, very close to that of a black body (incandescent lamps are effectively black bodies), dropping to negative values for some light sources. Low-pressure sodium lighting has a negative CRI; fluorescent lights range from about 50 for the basic types, up to about 98 for the best multi-phosphor type. Typical white-color LEDs have a CRI of 80 or more.The most common definition of CRI Ra is simply an average of the first 8 R values (R1 to R8). Other R values such as R9 and R12 are critical color samples that represent deep red and saturated blue, but are unfortunately not included in the regular CRI Ra calculation



CRI with 15 color comparisons (CRI is compared with only 8) of scale 100.

2.2 Extended CRI

Extended CRI is calculated as the average value of R1 through R14. Sometimes the symbol "Re" is used, where the letter "e" represents "extended." Notably, extended CRI captures the influence of saturated colors such as deep red (R9) and strong blue (R12) that general CRI does not.This is one of the criticisms of the general CRI, and it is therefore always a good idea to look at extended CRI and the specific R values when working on a project where color quality matters.

CRI R9 is one of the test color samples (TCS) used in the calculation of extended CRI. Many manufacturers will only report general CRI, however, which does not include the CRI R9 score. CRI R9 is therefore often useful supplemental score to judge a light source's color rendering ability, specifically as it concerns objects whose reflectance spectra contain red wavelengths.

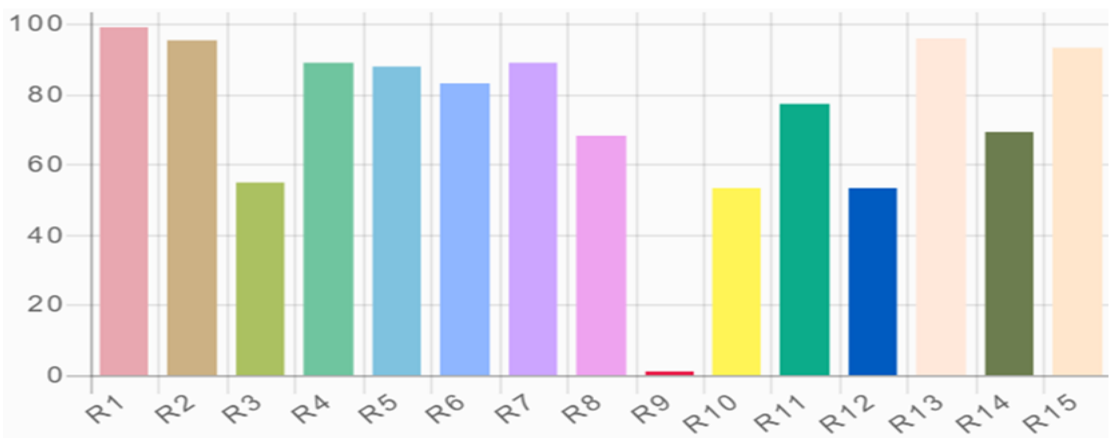
- **The CRI R9**

  R9 is the score that represents how accurately a light source will reproduce strong red colors."Accurate" is defined as similarity to daylight or incandescent bulbs, depending on the color temperature.Just like each of the CRI R value calculations, R9 is calculated by calculating the reflected color from a theoretical object.

- **Importance of CRI R9:**

CRI R9 is a very important metric because many light sources will be lacking in red content, but this fact will be hidden due to the averaging out of CRI calculations which do not include R9.

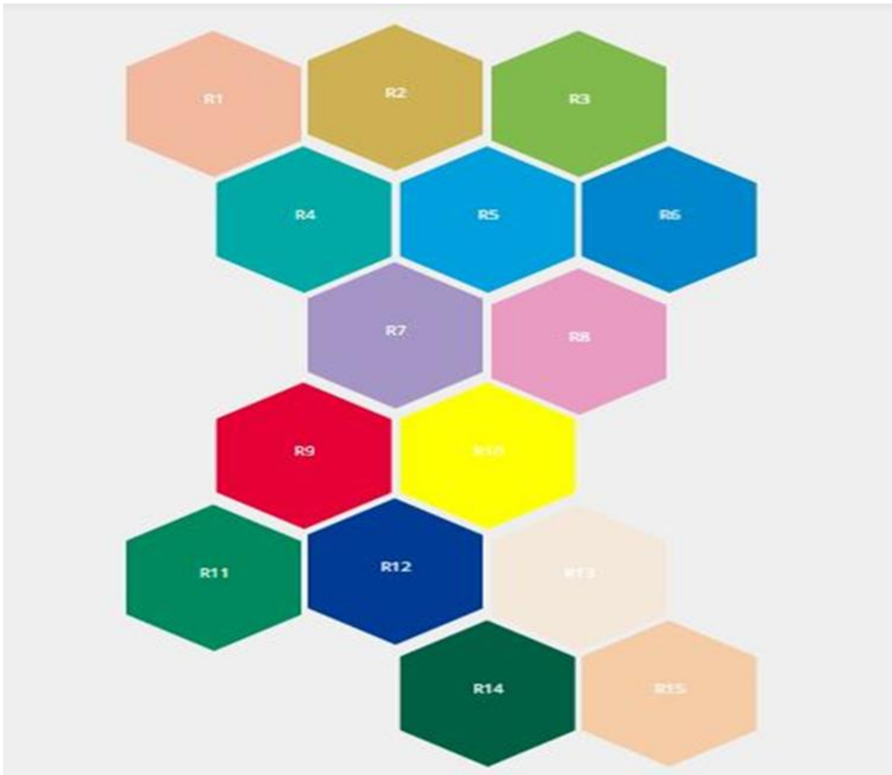
As the chart below shows, a light source can actually perform quite well with the first 8 test color samples, scoring quite well for R1-R8. For the general CRI Ra metric, this means that an LED with poor red color rendering can still get by with an 80 CRI (Ra) rating.



A closer look at the R9 value, however, reveals that the light will perform very poorly for red colors in particular

- **Importance of RED color:**

Red is a crucial color for many applications including photography, textiles and reproduction of human skin tones.Many objects that do not appear red actually are a combination of colors, including red. Skin tones, for example, are very much influenced by the redness of the blood that flows right beneath our skin.Therefore, a light that lacks red will make a person look pale, or even green. This can be problematic for medical applications where color appearance is critical for accurate diagnoses. In other applications such as photography, aesthetic appearance is crucial and many times cannot be corrected for even in post production and digital editing. When searching for a high color quality LED, be sure to inquire about the CRI as well as its R9 value.

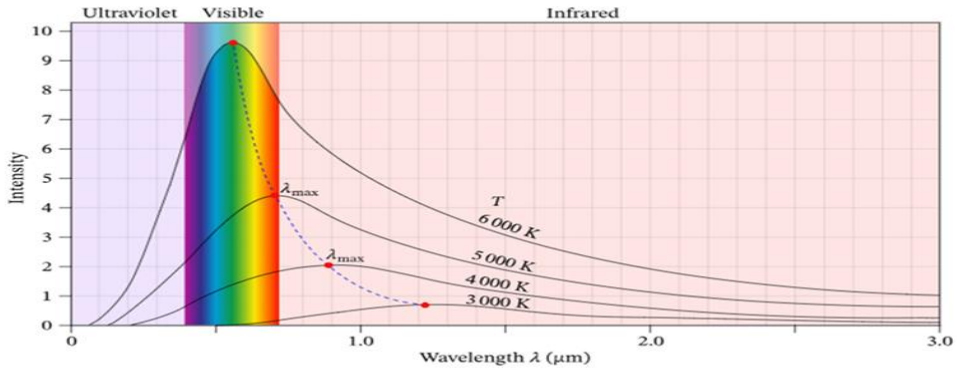


The 15 Color Swatches

2.3 Spectral Power Distribution (SPD):

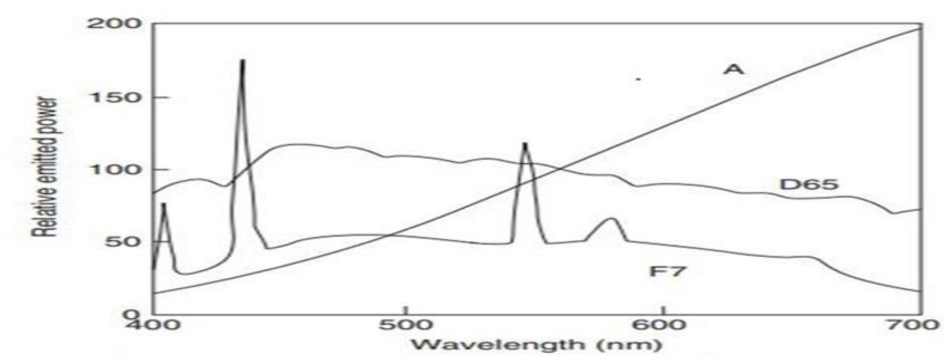
The numerical description of a light source is given by its spectral power distribution (SPD). This gives the emitted power within a unit wavelength interval as a function of the wavelength.

The spectral power distribution is the true "fingerprint" of a light source, as it is the key to how the light source renders colors. The image below shows the SPD of an ideal (blackbody) light radiator. The colored range represents its energy levels in the visible light spectrum.



SPD OF BLACKBODY LIGHT RADIATOR

For color measurement, a relative rather than an absolute SPD is adequate and it does not have to necessarily correspond to that of a real light source. The Commission Internationale de l’E´ clairage (CIE) has proposed several so-called illuminants with defined SPDs specifically for colorimetric purposes. For example, the SPD of CIE illuminant A corresponds closely to that of light from a tungsten filament lamp operating at a color temperature of 2856 K. Daylight is of course a major light source but is extremely variable. The CIE has defined the SPDs for a number of illuminants corresponding to typical phases of daylight, with color temperatures from 4000 to 25 000 K, the most common of which is CIE illuminant D65.For these illuminants, the label D represents daylight and the number of the color temperature in hundreds (65 represents 6500 K). The CIE has also defined the SPDs of a number of F illuminants that represent different types of fluorescent light.

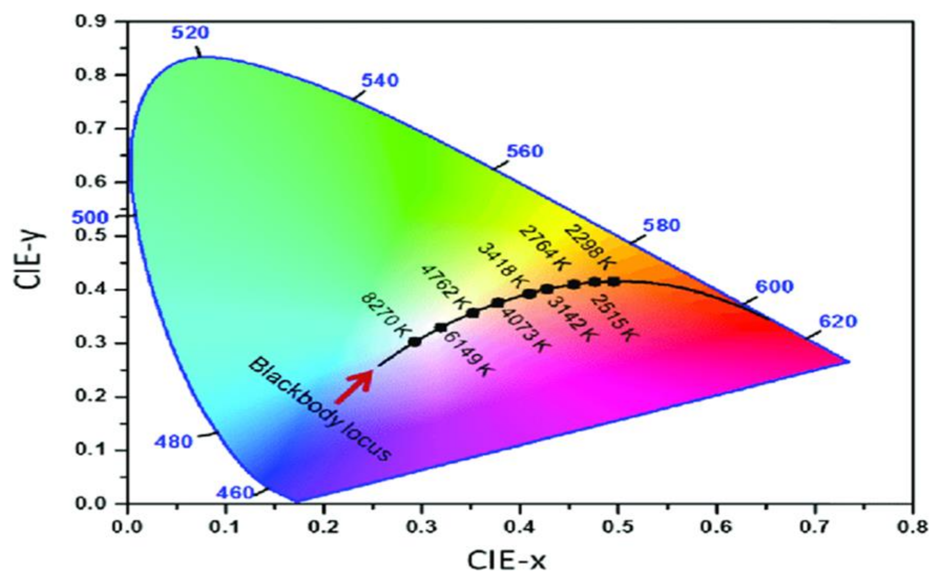


Relative Spectral Power Distribution Of CIE Illuminants A, D65 and F7

2.4 CCT and Duv

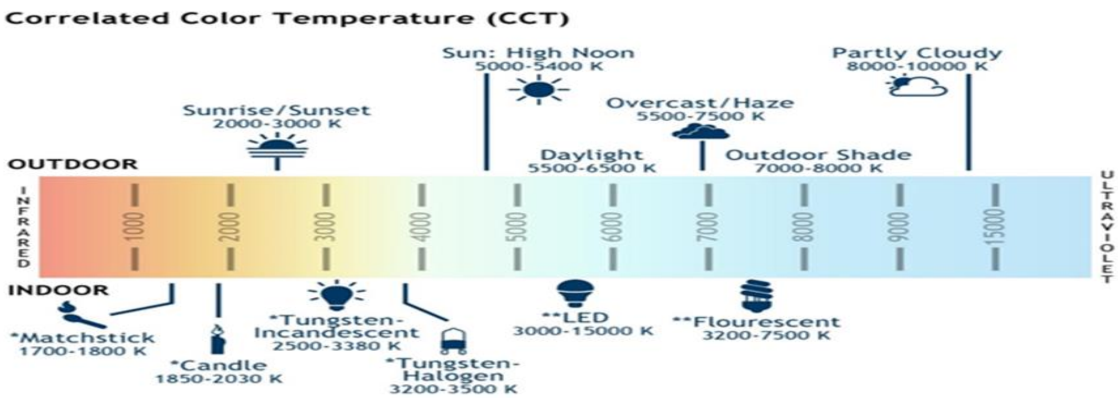
- **What is CCT?**

The CCT of LED luminaires indicate the color appearance of any white light emitted by a particular light source which is expressed by a single number. CCT is expressed in Kelvin (K) and helps to describe the relative warmth or cool of the emitted light. This does not refer to the actual temperature of the luminaire: the CCT numerical value describes the temperature to which a particular black body would need to be heated to glow in the same color as the luminaire. The CCT of a light source is the point on the Planckian locus that matches most closely(perceptually) to the chromaticity coordinates of the light—called its color temperature. If a light source is not a black-body radiator, but its chromaticity coordinates lie close to the Planckian locus, we can characterize its color by its CCT.



Chromaticity coordinates of white light in the CIE 1931 chromaticity diagram.

For example, if a black body was heated to 3,000 degrees Kelvin, it would glow in the same color as a luminaire having a CCT of 3,000 K. This concept is borrowed from physics and is a somewhat complex but practical way to assign a numerical value to the light color temperature. The diagram below compares the CCT of various light sources, including sunlight at different times of day and in different weather conditions, and various artificial light sources.



When we speak about CCT with regards to lighting, we are referring to the color of the white light. CCT is only applicable to white light, and is not used for colors like red, green, or blue. CCT stands for correlated color temperature, which is how we can tell what sort of white light a light source will produce. CCT is only a measurement of the color of light, this has nothing to do with the brightness (Lumens) or light quality (CRI).

- **Why is CCT important?**

The color of light has been proven to have a direct effect on the human brain. For example, a warm white light (2000k-3000k) will have a calming effect, and therefore is ideal for places like bedrooms, living rooms, & restaurants. Whereas a Cool White light (4000k-6500k) has a stimulating effect, and is therefore ideal for places of work, or where concentration is required. For example, office lighting in Australia is mostly 4000k, and many retail supermarkets use a 4000k or 6000k light source as it is beneficial to have stimulated customers or staff.

In typical day to day lighting design practice for residential and commercial lighting, you will typically only see products being used in the range of 3000k(Warm white) to 6500k(Daylight). Some specialist architectural applications where a very warm inviting atmosphere is required, you may see some products being used below 3000k. For example, a bar or restaurant may use a combination of 2700k LED strip lighting in the bar area, together with some low glare 2700k downlights to create a warm, inviting, and calm environment. You may also see some products being used above 6500k in the signage or aquarium industry, however this high CCT over 6500k will very rarely be used in architectural lighting.

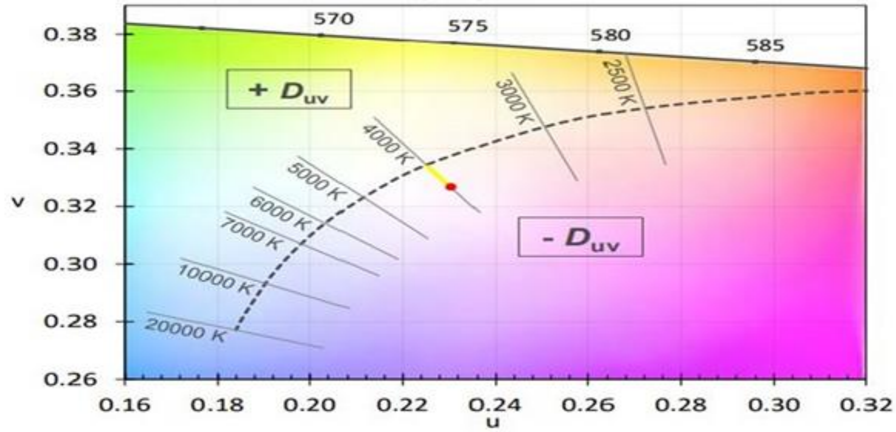
- **Limitations of CCT**

Although CCT has been widely used to evaluate light sources, it suffers from the loss of information caused by reducing often complex spectral power distribution shapes and two dimensional chromaticity coordinates (CCT is one dimensional) into a single number. Since chromaticity diagrams are two dimensional spaces, two coordinates are required to specify each unique point. As a result, two visually distinct light sources can have the same CCT. In addition, CCT calculations are based on colour matching functions devised to estimate colour precept matches made by standard observers under confined environmental conditions. The background and surroundings affect colour perception (e.g. simultaneous contrast). For example, a 4000 K light source may look warm next to a 6500 K light source, but it may appear cooler next to a 2700 K light source.

Research also shows that visual differences can be perceived among similar CCT sources. For example, observers can perceive a variation in light sources along isometric CCT lines (identical CCTs with different chromaticity coordinates), especially for high CCT light sources (Tcp> 4500 K). Since CCT inaccuracy increases with distance from the Planckian locus, measuring the chromaticity distance to the Planckian locus was suggested and a new term come into place that is Duv, the deviation from the plankian locus.So CCT without Duv can not provide the full information of a white light chromaticity that light.

- **Duv**

CCT being single dimensional and Chromaticity is of two dimensional. So, to represent a white light source another dimension is often missing, the distance from the Planckian locus to blended light source. Duv is defined in ANSI C78.377 for this purpose, but it is still not widely used. Duv value provides the information about the distance and direction of color shift from Planckian locus(yellowish/greenish or pinkish).The other term that is Duv sometimes gives the information about distance and no information about the direction of shift.By using CCT and Duv we can provide the full information about the chromaticity of the blended light source.



CIE 1960 (u, v) Chromaticity Diagram

2.5 IES Fidelity Index (R_f) and Gamut Index (R_g):

IES stands for Illuminating Engineering Society, which is the organization that developed the new and improved method called TM-30-20 (Previously TM-30-15) for evaluating light source rendition. Color science research backs this new method and provides an even more accurate measurement of color rendering.

Currently, TM-30-20 is used in conjunction with CRI, however it will eventually replace the CRI metric. The TM-30-15 method uses a Fidelity Index, Gamut index and Color Vector Graphic to evaluate the light source color rendition. The difference between the Fidelity Index of CRI and TM-30-15 method is that the latter uses 99 color evaluation samples (CES), instead of just 8.

- **Fidelity Index (R_f)**

  The Fidelity Index is used to measure the light source's closeness to a reference source, just like described in the CRI method. The scale using the TM-30-20 method is from 0 to 100 and uses 99 color evaluation samples. The use of 99 color samples versus just eight color samples allow a more statistically representative and reliable metric in showing how accurate the colors will be shown. The 99 colors in the TM-30-20 Fidelity Index were chosen from real world objects.

- **Gamut Index (R_g)**

The definition of the word ‘gamut’ is “the complete range or scope of something.” The Gamut Index, in lighting, is used to measure the increase or decrease in Chroma of a light source. Chroma is the quality of the color’s purity, intensity, or saturation. For instance, the color of a red fire engine is a high-Chroma red and a neutral gray is a low-Chroma color. An R_g score that is around 100 means that the light source can produce colors with a similar level of saturation as the sun at daylight (approx. 5600K/6500K). When looking at LEDs, to get an acceptable color quality, the score should be between 80 and 120; higher scores represent higher levels of saturation (the intensity of color). When the score is above 100, the color will be more intense than it’s natural color in the sunlight.

- **Color Vector Graphic**

This form of measurement reveals how certain colors appear with the observed light, whether the colors show up dull or more vivid. The Color Vector Graphic is an intuitive tool that shows which colors will be more or less saturated, or just right through a visual representation. Instead of through numbers, this graph shows you the changes of hue and saturation which is a great complement to the Fidelity and Gamut Indices.

Since the Fidelity and Gamut Indices are based on averages, you’re not able to tell which colors are saturated. This is where the Color Vector Graphic is important to understand if you have an application specific need for the LED lighting. The Color Vector Graphic used along with the values of Rf and Rg will help provide a more precise idea of how true colors will be with that light source.

SUMMARY OF TERMS

Below is a quick recap of what you can tell with these lighting measurement tools

- **CRI - Color Rendering Index** – How closely the observed light can render colors like the sun, using 8 color samples.

- **Fidelity Index (TM-30)** – How closely the observed light can render colors like the sun, using 99 color samples.

- **Gamut Index (TM-30)** – How saturated or desaturated colors are (aka how intense the colors are).

- **Color vector Graphic (TM-30)** – Which colors are saturated/desaturated and whether there is a hue shift in any of the 16 color bins.

- **CQS - Color Quality Scale** – An alternative to the unsaturated CRI measurement colors. There are 15 highly saturated colors that are used to compare chromatic discrimination, human preference, and color rendering.

CHAPTER-3 THE LEDs:

A light-emitting diode (LED) is a semiconductor devic (PN junction Diode) that emits light when a suitable voltage is applied to the leads; electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.An LED is a light source and it should not be confused with a light fixture or luminaire. An LED is a component of the entire fixture.

3.1 Working of LED:

As already mentioned that LED is a PN junction Diode so like an ordinary Diode it works when it is forward biased. In this case the N-type semiconductor is more doped than the P-type forming the P-N junction.

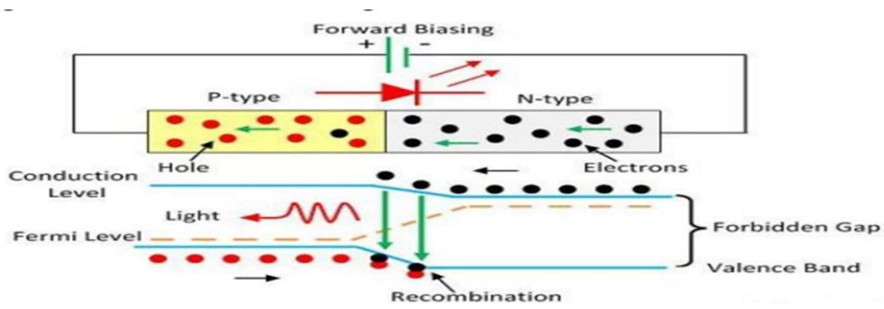
- Basically aluminium-gallium-arsenide (AlGaAs) material is used in LEDs. In its original state, the atoms of this material are strongly bonded. Without free electrons, conduction electricity becomes impossible here.By adding an impurity, which is known as doping, extra atoms are introduced, effectively disturbing the balance of the material.

  These impurities in the form of additional atoms are able either to provide free electrons (N-type) into the system or suck out some of the already existing electrons from the atoms (P-Type) creating ―holes‖ in the atomic orbits. In both ways the material is rendered more conductive. Thus in the influence of an electric current in N-type of material, the electrons are able to travel from anode (positive) to the cathode (negative) and vice versa in the P-type of material. Due to the virtue of the semiconductor property, current will never travel in opposite directions in the respective cases.

- From the above explanation, it’s clear that the intensity of light emitted from a source (LED in this case) will depend on the energy level of the emitted photons which in turn will depend on the energy released by the electrons jumping in between the atomic orbits of the semiconductor material.

- We know that to make an electron shoot from lower orbital to higher orbital its energy level is required to be lifted. Conversely, if the electrons are made to fall from the higher to the lower orbital’s, logically energy should be released in the process.

- In LEDs, the above phenomena are well exploited. In response to the P-type of doping, electrons in LEDs move by falling from the higher orbital’s to the lower ones releasing energy in the form of photons i.e. light. The farther these orbitals are apart from each another, the greater the intensity of the emitted light. Working of LEDs is shown below in Fig.



Working of LEDs

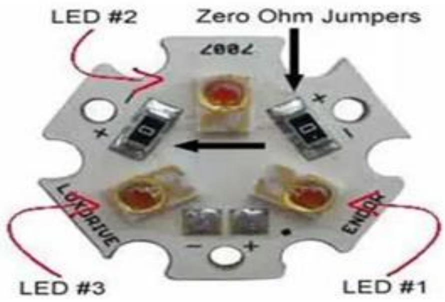
3.2 Different Types of LED (Light-Emitting Diode)

3.2.1 Miniature LEDs

These are mostly used nowadays. These are available in single shape and colour and are available in small sizes. It can be directly placed into a circuit board without the use of a heating or cooling device. These are classified into low-current, standard and ultra-high output depending upon various factors such as voltage, total watts, current, and manufacturer type. Miniature LEDs are used in small appliances such as remote controls, calculators and cell phones.

3.2.2 High-Power LEDs

These uses of LEDs results in high output compared to normal LEDs. The light emitted is measured in terms of lumens. These are again categorized based on luminous intensity, wavelength and voltage. These have a danger of overheating hence a heat-absorbing material is used to cool it down. High-Power LEDs are used in high-powered lamps, automobile headlights, in various industrial and mechanical equipment.

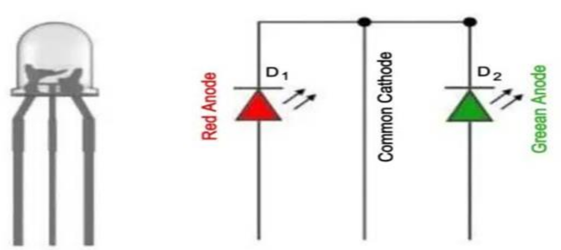


3.2.3 Flash LED

With a normal LED, it contains an integrated circuit which flashes the light at a particular frequency. These are directly connected to a power supply without the help of series resistors. It is used in signboards, vehicles etc.

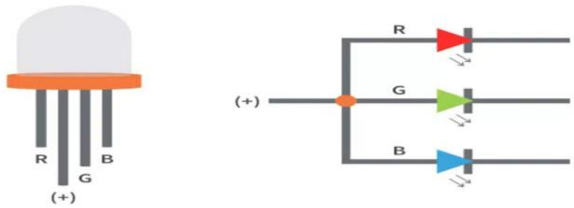
3.2.4 Bi and Tri-Color

Bi-color LED lights consist of two light-emitting dies in a single case. The wiring is inversely parallel which means one is in the forward direction and another in backward which makes one die lit at one time. The flow of current alternates between two dies which results in color variation. Tri-Color LED lights design lets the two dies to lit separately or together producing a third color.



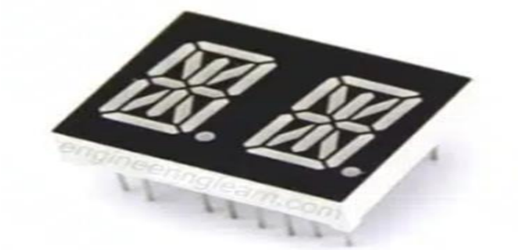
3.2.5 Red Green Blue LEDs

These emit red, green and blue light and also combine these three primary colors and produce a new color. These are used in accent lighting, lights shows and status indicators.



3.2.6 Alphanumeric LED

These consist of segments which offer greater flexibility and lesser power consumption. In it, it has various types of LEDs such as:14 and 16 segment- they cover full 26 characters of the Roman alphabet in uppercase and with numerals 0-97 segment- covers all numbers and limited set of letters Matrix segment- covers full alphabets (upper and lower), all number and a full variety of symbols.



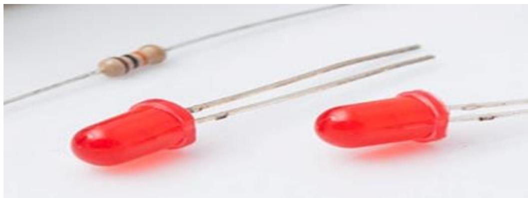
3.2.7 Lighting LED

These LEDs use an aluminium/ceramic body which provides heat dissipation. One example is the Edison light bulb design.

3.3 LED Technology

Fundamentally, there are three different types of LED technology that are used in LED lighting – **DIP, SMD and COB.**

3.3.1 Dual In-Line Package (DIP) LEDs



DIP LED Lights

DIP LED chips are the original LED chips and what many recall when they think of LED lighting. While they're older than their younger counterparts, DIP LED chips are still in use today and are more often found built-into electronics due to their diminutive size. They're not very powerful though, and can only emit a limited amount of brightness.

3.3.2 Surface Mounted Diode (SMD) LEDs

SMD LED Spotlight Bulb

These are mounted and soldered onto the circuit board, and are probably the most common type of LED chip available. They are brighter than their DIP predecessors and are also smaller, so even more versatile when it comes to encasing them within smaller electronics or across different types of lighting, such as strip lighting. You can put three diodes on a single SMD chip, which means you can create a range of different colors, offering consumers greater variety. This has been a massive development in the LED market. The two most common types of SMD chip sizes are SMD 3528 and SMD 5050 – the former is 3.5mm wide and the latter is 5mm.

3.3.3 Chip on Board (COB) LEDs

COB LED Spotlight Bulb

These chips represent the latest development in LED technology. COB LED chips are the brightest out of the three, typically being able to pack nine or more diodes onto a single chip. What does this mean for LED lighting? Well, firstly, it improves the brightness-to-energy output, thus increasing lighting efficiency. This also means they can be used across a wide range of different types of lighting. However, it's worth noting that due to the circuitry makeup of a COB LED chip, they're unable to emit an eclectic range of different colors.

The developed light source consists of 4 strings of LEDs and having the strings of Cool White,Warm White,Green and Blue LEDs.There are 12 numbers of Warm white and Cool white LEDs in series in first string and second string respectively.In the third and fourth string there are 10 numbers of Green and Blue LEDs in series respectively.So there are 44 total LEDs are installed in the developed light source.The Warm white and cool white LEDs are of SMD type and Green and Blue LEDs are of high power type LEDs.The warm white and cool white LEDs are of same specifications that is 3V,700 mA (total power of 24 LEDs is=24x3x0.7=50.4W and the green and blue LEDs are of almost same specifications of 2.5V,350 mA(total power of 20 LEDs is=20x2.5x0.35=17.5W).So total wattage of the developed light source is almost 67W.

CHAPTER-4 THE LED DRIVER THEORY

In the field of lighting, light-emitting diodes (LEDs) have become potential technology as energy efficiency and sustainability become more crucial factors. This is due to its excellent energy efficiency, long longevity and low environmental effect. To fully satisfy the potential of LEDs, economical LED drivers are necessary to ensure the best performance, longest lifespan, and least amount of energy consumption.

An LED driver is an electronic device or circuit that regulates and controls the electrical power supplied to light-emitting diodes (LEDs). It ensures that the LEDs receive the appropriate voltage and current necessary for proper operation, brightness control, and longevity. LED drivers play a crucial role in converting and managing the power supply from various sources to match the specific requirements of LEDs, which helps achieve consistent and efficient illumination.

4.1 Constant current and constant voltage led driver

Irrespective of any topologies mainly there exist two types of LED drivers such as

i. Constant-Current (CC) LED driver and

ii. Constant-Voltage (CV) LED driver.

In addition to this in some cases the type of driver called AC LED driver can also be used. Each driver is designed efficiently in order to operate the LEDs with different kinds of output requirements.

In constant current LED drivers the output current should be constant in the system whereas voltage must be varied depending on the LED load [11]. For example, the ratings of CC LED driver are "output current 700mA, output voltage (4-13V DC) range". Presently in the market Constant Current drivers are available with following ratings 350mA, 700mA or 1A, for example, the ratings of CC LED drivers are "output voltage 12V DC or 24V DC, output current maximum 1.04A for 24V DC".

In constant voltage LED drivers the output voltage should constant in the system whereas current must be varies depending on the LED load[11] i.e. The multiple loads are connected parallel across the output side of the driver until to get maximum output currents. The constant voltage drivers are available with mentioned voltage ratings such as 10V, 12V or 24V. AC LED driver is mainly used in LED bulbs in which the system contains an internal driver that converts the electrical current from AC to DC [12]. The main function of the driver is to register lower wattage LED bulbs and step down its voltage in order to meet the output requirements. Usually, these are available with 12V or 24V.

The available voltage in our hand is alternating, that is AC voltage in nature. But LEDs are required to be operated in DC. The available AC voltage is very high but the required DC voltage is low. To convert this high voltage AC to low voltage DC the LED Driver is required.

4.2 Single Stage and Multi Stage LED Driver

Generally the LED Drivers are classified into two categories irrespective of the converter topologies as - Single Stage and Multiple Stages.

1) **Single Stage:** Only one stage The Power Factor Correction (PFC) stage, known as the LED driver, serves as the link between the input and the LED string, used in low and medium power applications. Single stage Drivers profit from having fewer components. However, because Symbols have fewer design degrees of freedom, getting acceptable properties in terms of power factor, THD, dimming range, and output current ripple is difficult. When the variable range of one parameter, such as the input voltage, is constrained, single-stage topologies are frequently preferred.

2) **Multiple Stage:** Figure below shows the concept of multiple stage LED drivers. Single stage approach usually fails to fully comply with requirements on the power factor, THD, life span, efficiency and output current ripple. Multiple stage approaches on the other hand, can introduce more design flexibility in achieving the aforementioned performance factors.

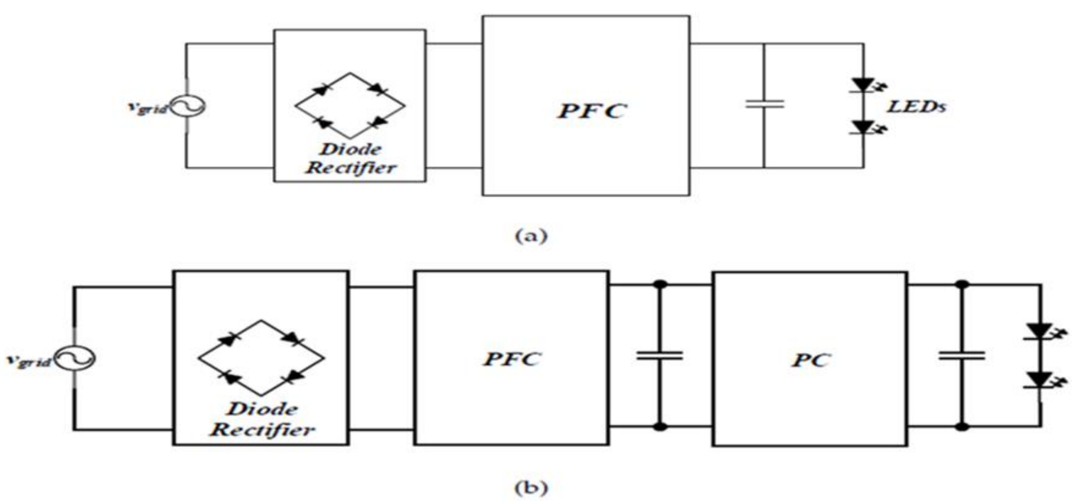


Figure 3: (a) Single Stage (b) Multiple Stages

4.3 Isolated and Non Isolated LED Driver

All of these single-stage and multistage DC-DC converters lack isolation and are therefore unsafe for use around people. So isolation is a very important factor for safety purposes. According to the isolation of the LED Driver from input to output the Driver is classified as Isolated and non-isolated LED Driver Topology.

1) **Non-isolated Driver Topology**

The input power is directly applied to the load after step-down, the input and output are directly connected through electronic components. The input and working voltage are not isolated. When in contact with the human body, it is prone to electric shock hazard. In the power topology, non-isolated power supplies mainly include Buck, Boost, Buck-Boost and so on.

2) **Isolated Driver Topology**

It refers to the electrical connection between the input and output through a transformer, the transformer is used to reduce the high-voltage voltage to a lower voltage, and rectify it to a DC output. There is no direct connection between the primary coil and the secondary coil, so there is no danger of electric shock. In the power supply topology, there are mainly various flybacks with isolation transformers, forward excitation, half bridge, LLC, etc.

The easiest way to distinguish is to look at the size, parameters, and price, as well as differences in efficiency, stability, and safety which are more specific for engineers.

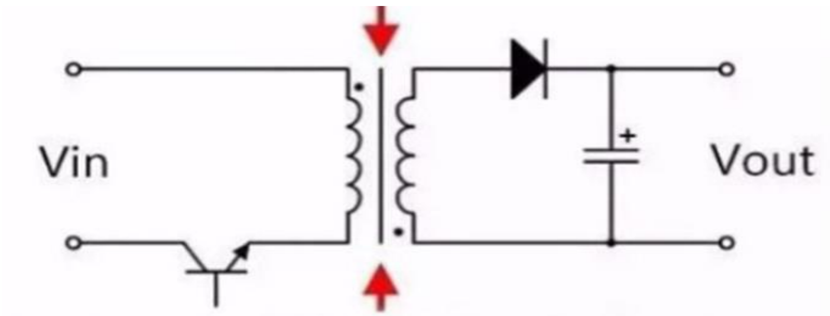
- **Volume** Non-isolated drivers are generally small in size. In order to reduce transformers, the minimum material design framework is used to achieve the same product functions.

- **Price** The price of an isolated driver is higher than that of a non-isolated driver. Due to the lack of transformers and lower cost prices, non-isolated power supplies are mainly used in more economical types of lamps, widely acceptable in areas where they pay attention to cost. The cost of isolated drive power is high, but its stability and safety are high, which are very popular in the high-end market.

- **Parameters** Non-isolated led drivers have a large power range and a wide voltage range, while isolated led drivers have a small power range and a much narrower voltage range.

- **Stability** The non-isolated led driver is worse than the isolated power supply. The reason is that the non-isolated circuit design is very sensitive to surges and shocks. The instability and instability of the state grid causes the LED chip to be overloaded and damaged. In order to solve this problem, a varistor is essential in the design of a non-isolated LED drive circuit. Compared with non-isolated power supplies, isolated LED drivers are safer due to the MOS protection in the circuit design.

- **Safety** Isolated the led driver means that the input and output terminals are electrically connected through a transformer. The conversion process of the transformer is: electromagnetic-electricity, not grounded, so there is no danger of electric shock; non isolated driver in power circuit that is directly added to the LED load through the input and output through the electronic components, there is a risk of electric shock.



With The Transformer, Input and Output are not directly Connected

- **Efficiency** Non-isolated LED Driver uses electronic equipment to lower the voltage. Due to the avoidance of transformer losses, the power efficiency of non-isolated LED drivers is higher than that of isolated LED drivers. The electrical efficiency of non-isolated LED drivers can reach 90%, while the efficiency of isolated power supplies using transformers is 86-88%.

Over all the other DC-DC converters, the flyback converter has a variety of benefits. A single switch flyback converter is easy to design, has fewer parts, takes up less room, is quieter, and is more affordable. In addition to providing electrical isolation, the flyback transformer also allows for the adjustment of output DC voltage by varying the turns ratio. It is possible to have numerous outputs by employing a transformer. Since the flyback transformer really serves as a storage inductor, a separate inductor is not necessary, which is a significant advantage of flyback converters over conventional isolated converters.

4.4 Topologies Used For Led Driver Design

4.4.1 Buck Topology Based LED Driver

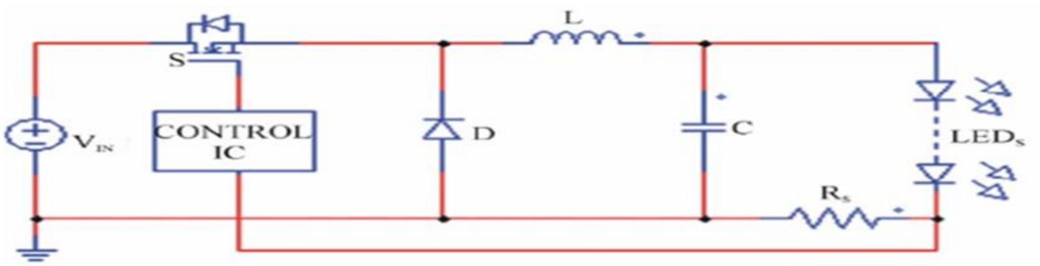
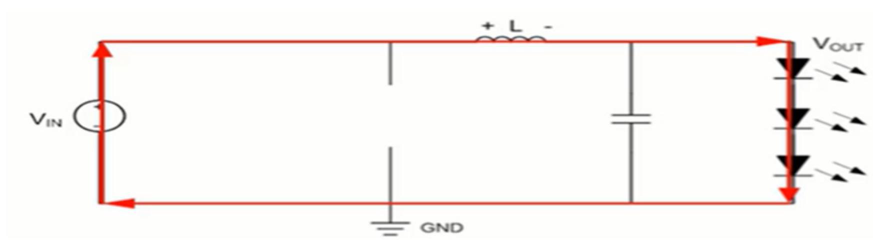


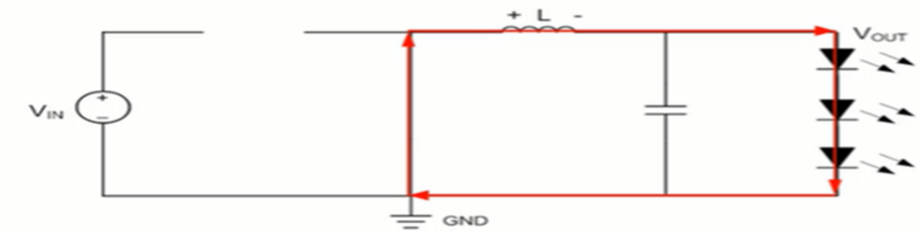
Fig-7: Circuit Diagram of Buck Converter based LED driver

Operating Principle of Buck converter based LED driver

- Mode1: When the switch is on and Diode is off, the inductor stores energy as current flows from source to inductor and into the load. Voltage drop across the inductor reduces the output voltage.

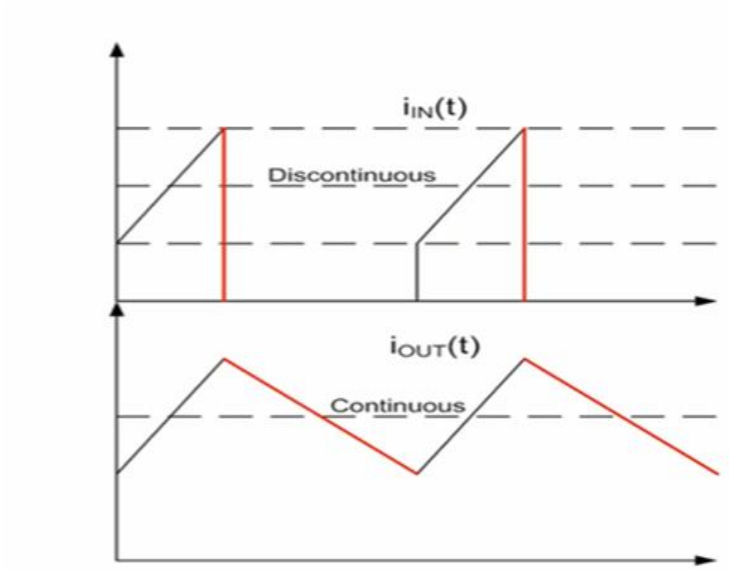


- Mode2: When the switch is off and Diode is on, the source is disconnected and the stored energy in the inductor releases and charges the capacitor and provides current to load which keeps the output current continuous.



A sense resistor in series with the LEDs is added to measure the current.

Waveform of buck converter based LED driver



- **Advantages of Buck converter based LED driver**

1. The advantages of using a buck topology converter include continuous output current, which allows for the best dynamic control of LED current.

2. This also means that the capacitor is not necessary to provide energy for the output and is only used to reduce the output ripple. This means that the capacitor can be reduced or even eliminated.

3. Buck tend to have simplest control Architecture.

4. Handles short to input and ground well.

- **Limitations of Buck converter based LED driver**

1. Discontinuous input current from the switching turning on and off. The transition from zero to peak current at the input causes conducted electromagnetic emissions which will require additional EMI filtering to mitigate.

2. A buck device also cannot increase the output voltage, so the number of LED strings that can be supported is limited by the input voltage.

- **Application of Buck converter in automobile LED headlights**

A buck converter based Driver is used to feed a load of high power LEDs. The load is divided into five high power LEDs (10W). In automobile lighting systems rapid changes of lighting are required (power changes), therefore the buck converter must deliver constant voltage levels to changes in power and further the current necessary to maintain a flow of light required.

The LED as power load is composed of several LED arrays (series, parallel, and series-parallel) to get high power and the voltage and current supply of these arrangements is very variable.

Advantage of using LEDs in the headlights of cars, between them the color temperature of LED lamps is approx. 5.500°>K. White LEDs are now considerably closer to daylight (approx. 6.000 ºK) that xenon light (approx. 40000ºK) [2], due to these, less fatigue in the driver is generated, as this type of light is closer to daylight.

Another benefit is that since the heat is concentrated at the base of the LED, non-emission surfaces can be employed without impacting light emission from sinks.

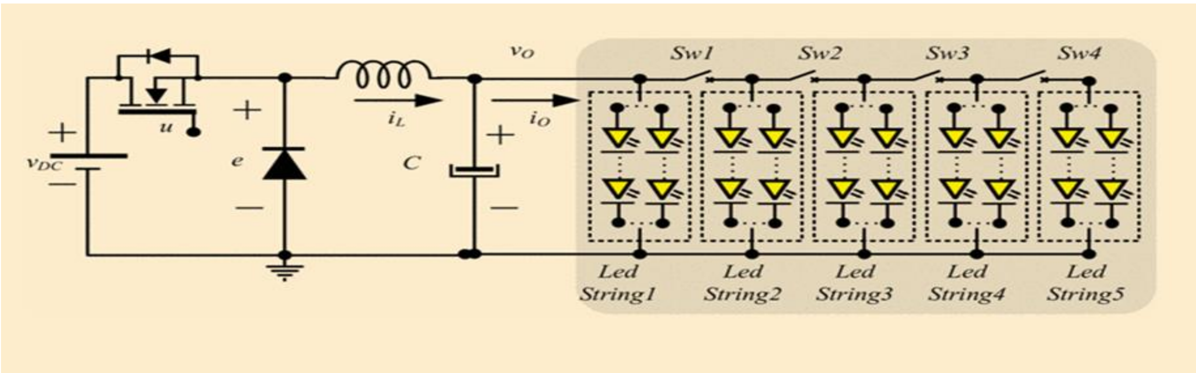


Fig-8: Driver based on Buck converter used for high power automobile LED Headlight

- **Buck Converter Based IC-1(LM5017)**

The LM5017 is a 100-V, 600-mA synchronous step-down regulator with integrated high side and low side MOSFETs. The constant on-time (COT) control scheme employed in the LM5017 requires no loop compensation and provides excellent transient response.

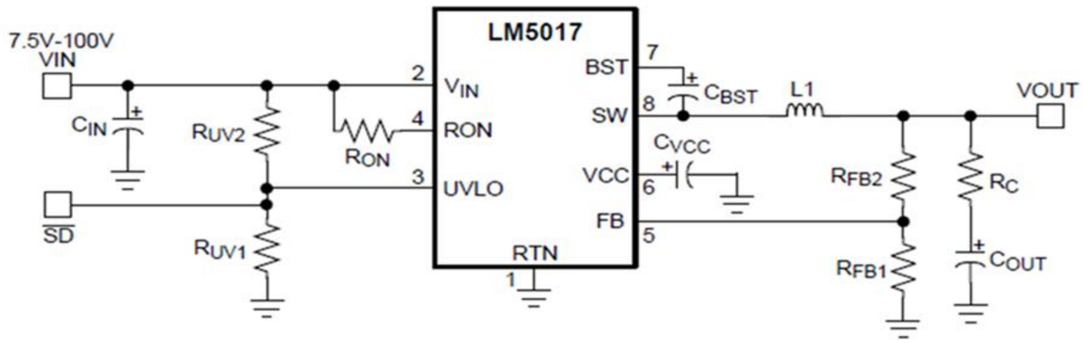


Fig-9: Typical Application Diagram

- **Buck Converter IC-2(A5975AD)**

The A5975AD is a step-down monolithic power switching regulator with a minimum switch current limit of 3.1A.So it can easily deliver up to 2.5 A DC current to the load depending on the application conditions. The output voltage can be set from 1.235 V to 35 V.

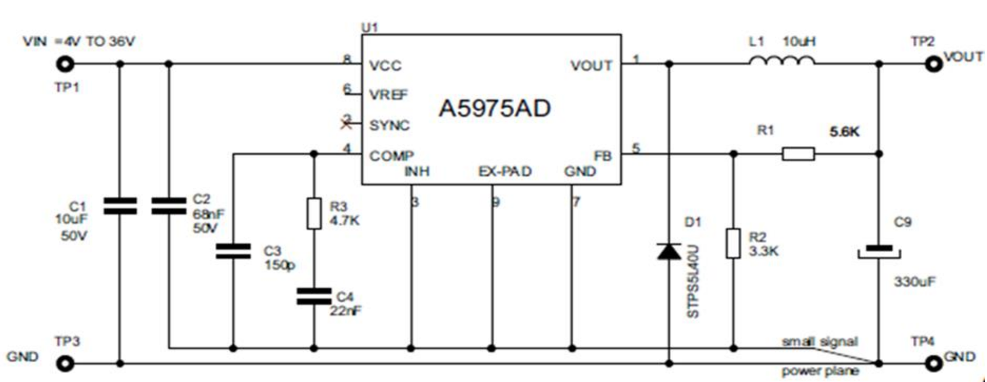


Fig: Typical Application Diagram

4.4.2 Boost Converter Based LED Driver

Sometimes designers need to have more output voltage than they have voltage to start with. They need to increase their voltage from low to high. Such a topology calls for a DC/DC boost (step-up) converter.

A single-stage LED driver integrating a boost converter with a half-bridge LLC resonant converter has been proposed. This topology is composed of a boost power factor correction circuit operating in a discontinuous conduction mode and an isolated LLC circuit unit with soft-switching characteristics

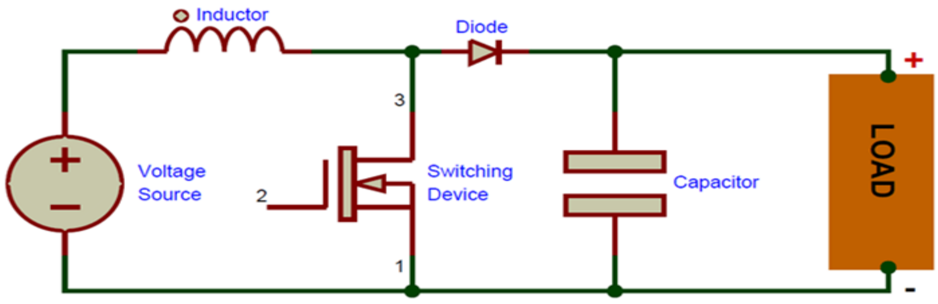
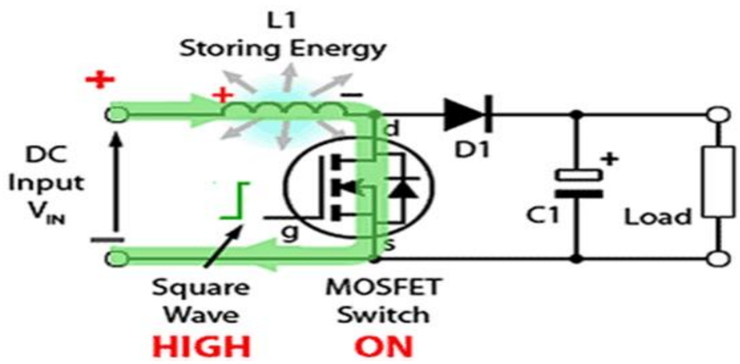


Fig-10: Circuit Diagram of Boost Converter based LED driver

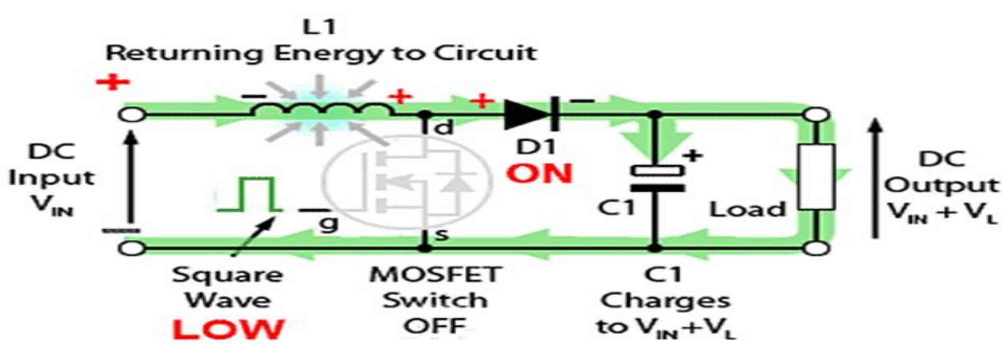
- **Working of Boost converter based LED driver :**
  - **Mode-1 : Switch is ON**

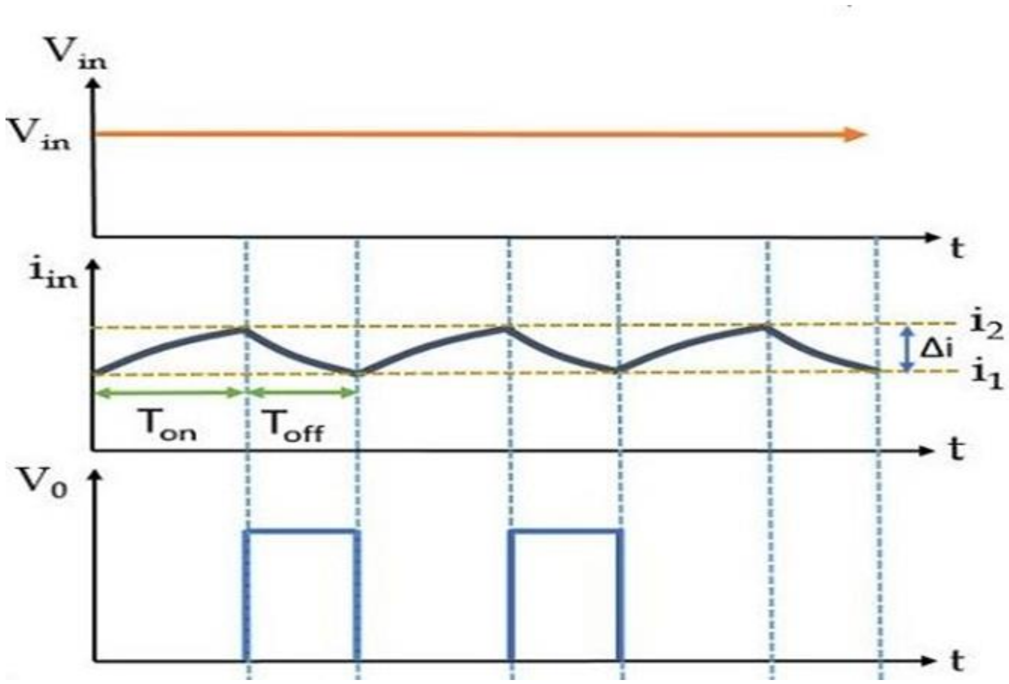
    Inductor stores Energy and no current flows through the load so output voltage becomes zero and the source is connected through the Switch directly.



- **Mode-2 : Switch is OFF**

  The stored Energy of the inductor is released and the stored energy of mode-1 is delivered to the load through the Diode





Waveforms of Boost converter based LED driver

- **Advantages of Boost converter based LED driver**

1. Continuous input current which reduces the input EMI filtering necessary compared to the buck.
2. This switches to ground reference which also makes it simple to drive the FET.
3. Handles Short to input.

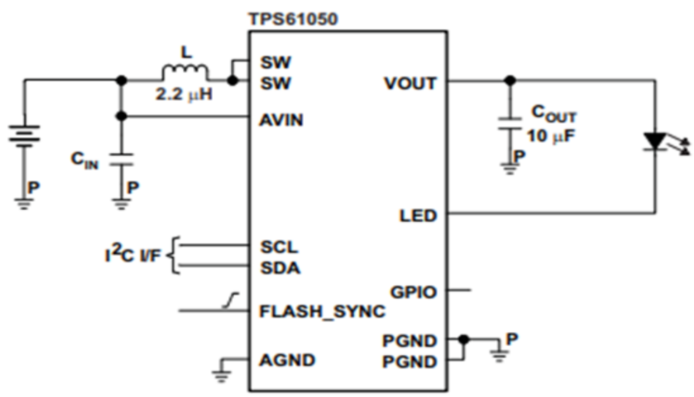
- **Limitations of Boost converter based LED driver**

1. Discontinuous output current, which means that an output capacitor is required to maintain the current. The output cap also helps minimize EMI and the LED switching ripple which may be needed to meet that peak to peak ripple requirements of the LED, but can make dynamic switching more difficult.
2. Discontinuous output current also creates more differential mode noise on the output, which turns into common mode noise causing higher radiated emissions

3. Only step up the input voltage. And finally, a boost converter does not handle short to ground conditions well.

- **BOOST CONVERTER IC (TPS61050, TPS61052)**

The TPS6105x device is based on a high-frequency synchronous-boost topology with constant current sink to drive single white LEDs. The device uses an inductive fixed-frequency PWM control scheme using small external components, minimizing input ripple current.



Typical Application Diagram

4.4.3 Buck Boost Based LED Driver

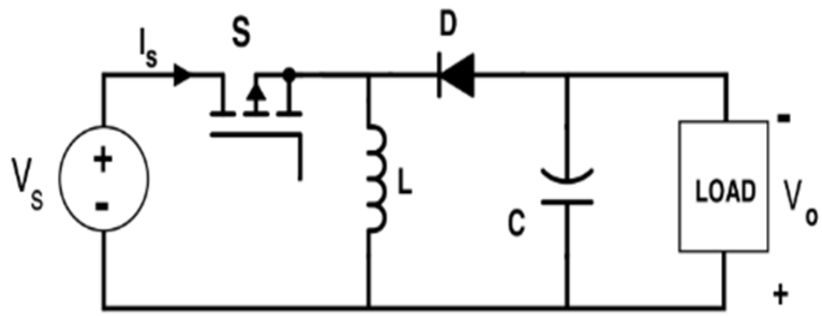
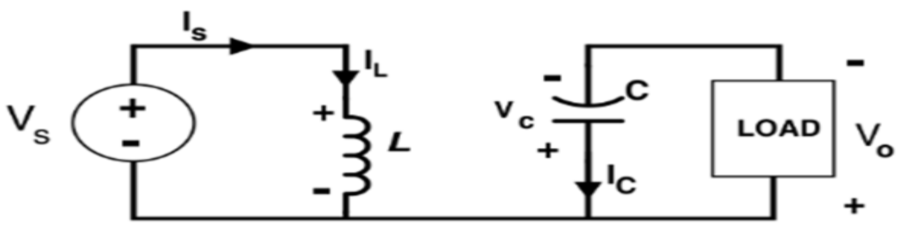


Fig-10: Circuit Diagram OF Buck Boost Converter based LED driver

- **Working of Boost converter based LED driver :**

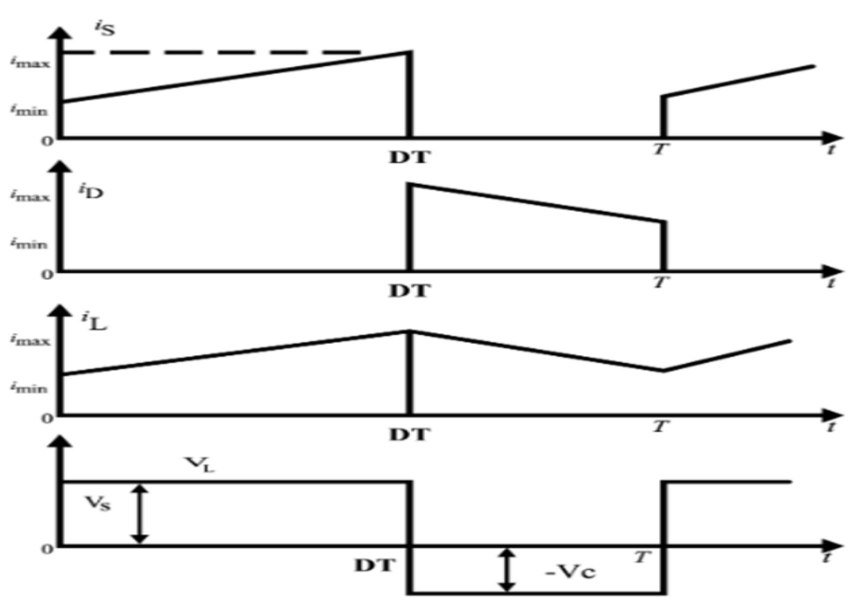
  - **Mode-1 : Switch is ON**

    Inductor stores energy and capacitor supply the load current by discharging through load.



  - **Mode-2 : Switch is OFF**

    The Inductor releases the stored Energy of mode-1 to the load and also capacitor and the capacitor charges.



Waveform of Buck Boost Converter Based LED Driver

- **Advantages of Buck Boost Converter based LED driver**

1. The main advantage is that it can adjust the output voltage by changing the duty cycle that can be higher or lower than input voltage due to the step-up and step-down character. This means the second power stage can be eliminated.

2. In order to get over the drawbacks of buck or boost PFC circuits, some research works concentrate on the cascaded buck–boost mode. When the input voltage is higher than the output voltage, the buck mode is working. Otherwise when the input voltage is lower than the output voltage, the boost mode is working

- **Limitations of Buck Boost converter based LED driver**

1. 1. Main disadvantage is the discontinuous input and output current, which means this topology has the poor input EMI performance of buck and the poor output EMI performance of the boost.

2. Discontinuous output means an output capacitor is required to maintain the current.

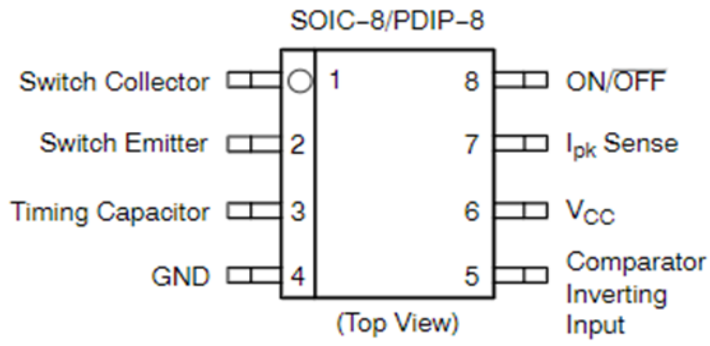
3. This method complicates the PFC control method In general, boost works in DCM to obtain a nearly unity PF that can easily be controlled. But for buck–boost circuits, there are still some disadvantages like output voltage polarity inversion. In addition, for integrated-stage LED drivers, when buck–boost Topology is adopted as the forestage PFC, because of the voltage inversion feature, the integrated design process may be more or less complex depending on the selected topology for the second stage. Therefore, the integrated design process may be more or less complex.

4.3.5 Applications of Buck boost converter

1. It is used in the self-regulating power supplies.
2. It has consumer electronics.
3. It is used in Battery power systems.
4. Adaptive control applications.
5. Power amplifier applications.

- **Buck Boost Converter IC (NCP3066, NCV3066)**

The NCP3066 is a monolithic power switching regulator optimized for LED Driver applications. Its flexible architecture enables the system designer to directly implement step−up, step−down, and voltage−inverting converters with a minimum number of external components for driving LEDs.

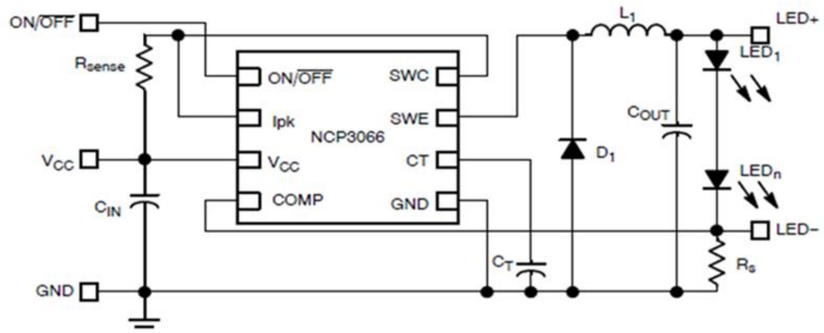


Pin Diagram (NCP3066)

Pin-6: V_{CC}, Voltage Supply Pin-4: GND, Ground Pin Pin-1: Switch Collector

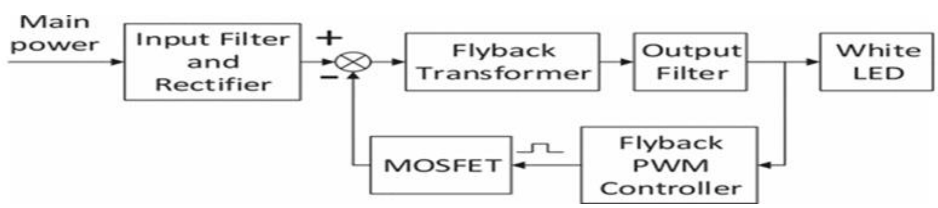
Pin-2: Switch Emitter Pin-3: Timing Capacitor Pin-5: Comparator Inverting Input

Pin-7: I_{pk} Sense, Peak Current Sense Input Pin-8: ON/OFF



Typical Application Circuit

4.4.4 Flyback Converter based led driver



Block Diagram for Flyback Converter Based LED Driver

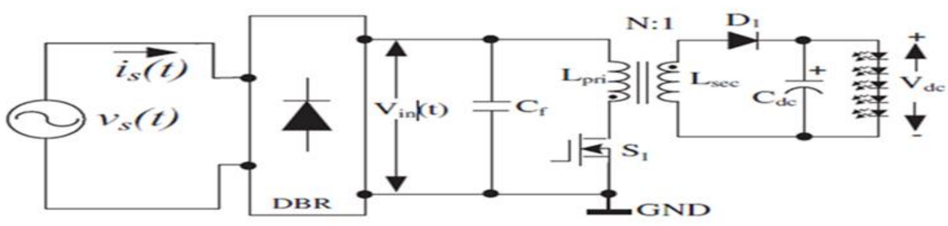
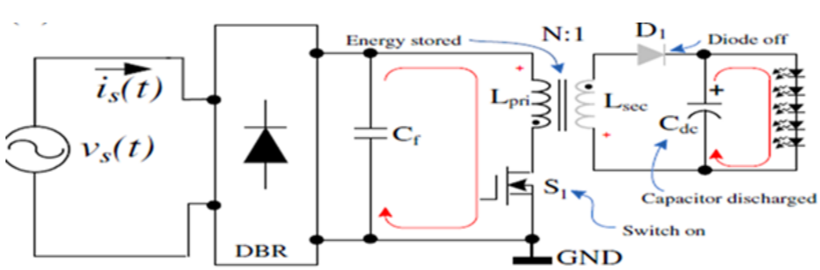
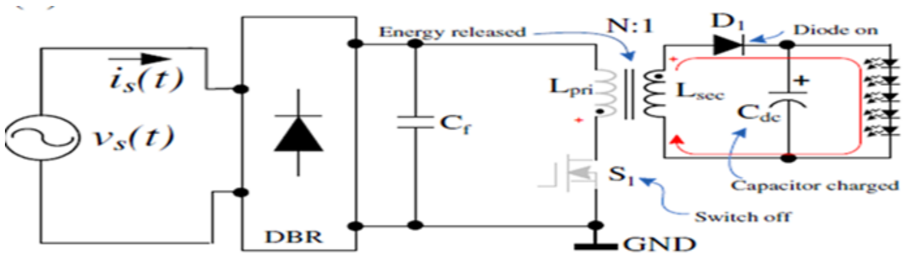


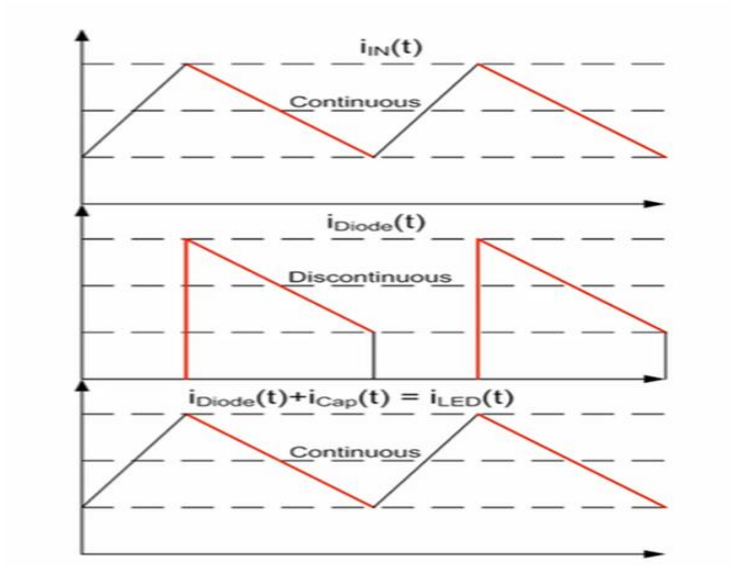
Fig-12: Circuit Diagram for Fly back Converter

- **Working Principle of Flyback converter based LED driver:**
  - **Mode1:** Switch is ON, Energy is stored in the inductor of the Transformer and Capacitor releases the previously stored energy and supplies the current to the load.



- **Mode-2:** Switch is OFF, Inductor releases the previously stored energy to the Capacitor and supplies current to the load.





Waveforms of Flyback converter based LED driver

- **Advantages of Flyback converter based LED driver**

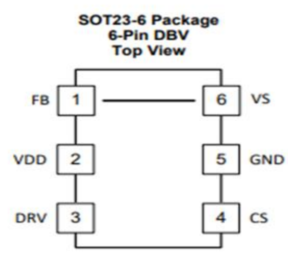
1. The primary is isolated from the output Capable of supplying multiple output voltages, all isolated from the primary.
2. Ability to regulate the multiple output voltages with a single control.
3. The Flyback converters use very few components compared to the other types of SMPSs.

- **Limitations of Flyback converter based LED driver**

1. Flyback converter requires additional snubber circuit to overcome leakage current of inductor.
2. In the Flyback converter the RMS current rating of the capacitor used in output is high.
3. Flyback converter has poor efficiency and is a pulsating source current

- **Flyback converter IC(UCC28742)**

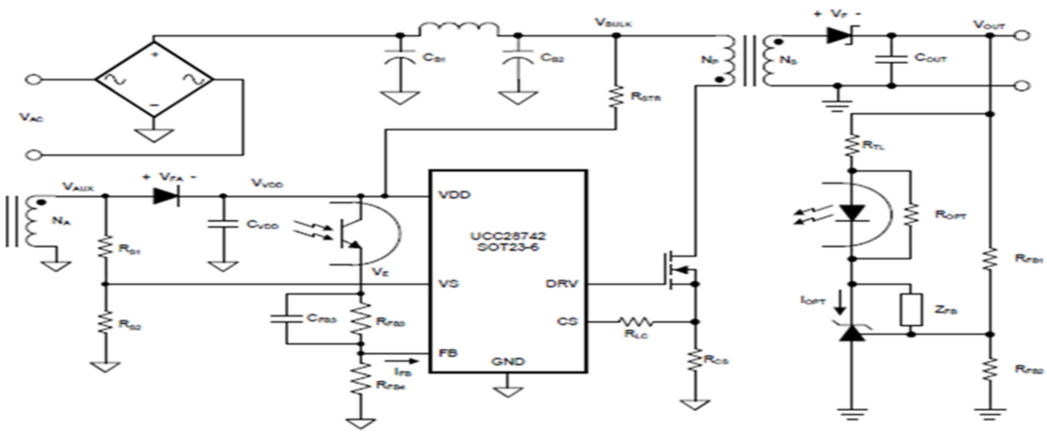
The UCC28742 off-line flyback controller is a highly integrated, 6-pin secondary-side regulated PWM controller for efficient AC-to-DC power supplies. It is an isolated-flyback power-supply controller that provides Constant-Voltage (CV) using an optical coupler to improve transient response to large-load steps. This device processes information from optocoupled feedback and an auxiliary flyback winding for high-performance control of output voltage and current.



Pin Diagram (UCC28742)

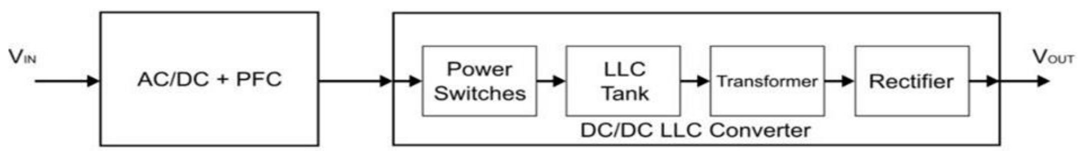
Pin-4: CS (Current Sense), Input Pin;   Pin-3: DRV, drive the gate of MOSFET, Output Pin

Pin-1: FB,Feedback Pin,Receivesinput from the optocoupler output,Input Pin; Pin-5: GND Ground Pin-2: V_{DD} Bias Supply,InputPin ; Pin-6: VS,Voltage Sense,Input Pin

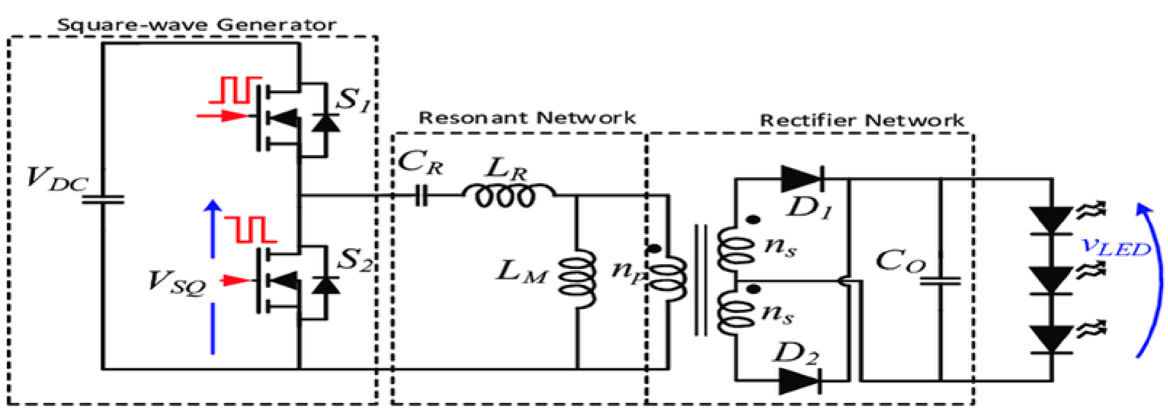


Typical Application Diagram

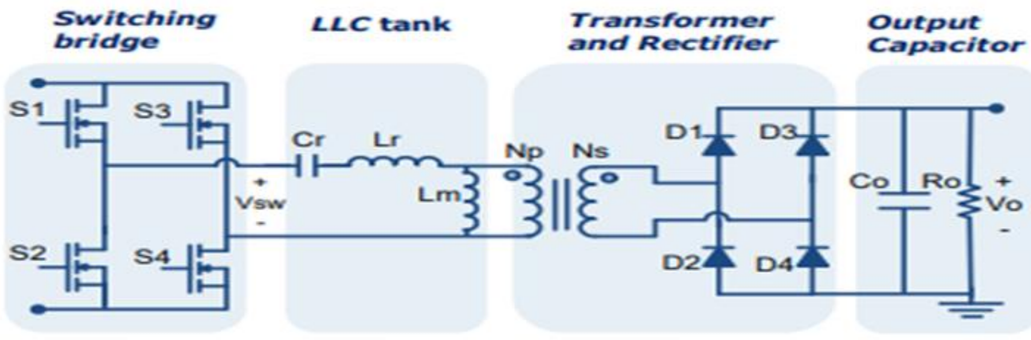
4.4.5 LLC Resonant Converter Based LED Driver



Block Diagram for LLC Resonant Converter Based LED Driver



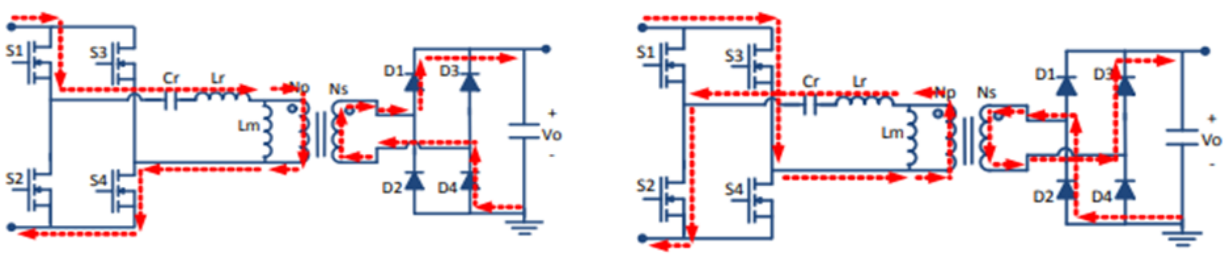
Circuit Diagram of LLC Resonant Converter (Half Bridge) based LED Driver



Circuit Diagram of LLC Resonant Converter (Full Bridge) based LED Driver

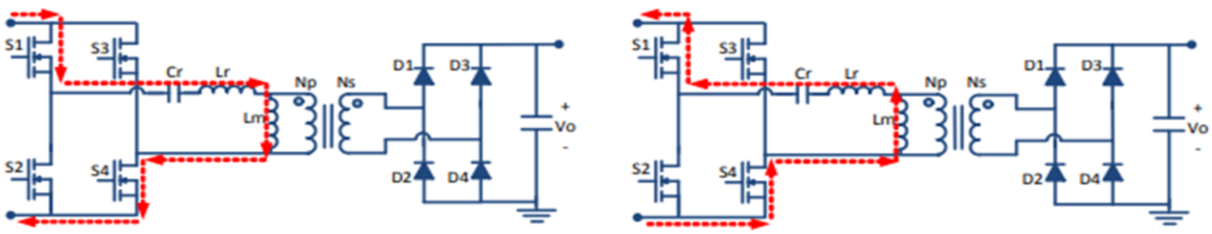
- **Working of LLC Resonant converter based LED driver :**

1. **Power Delivery Operation:** It occurs twice in a switching cycle; first, when the resonant tank is excited with a positive voltage, so the current resonates in the positive direction in the first half of the switching cycle, and second occurrence is when the resonant tank is excited with negative voltage, so the current resonates in the negative direction in the second half of the switching cycle, the equivalent circuit of this mode is shown in Figure below:

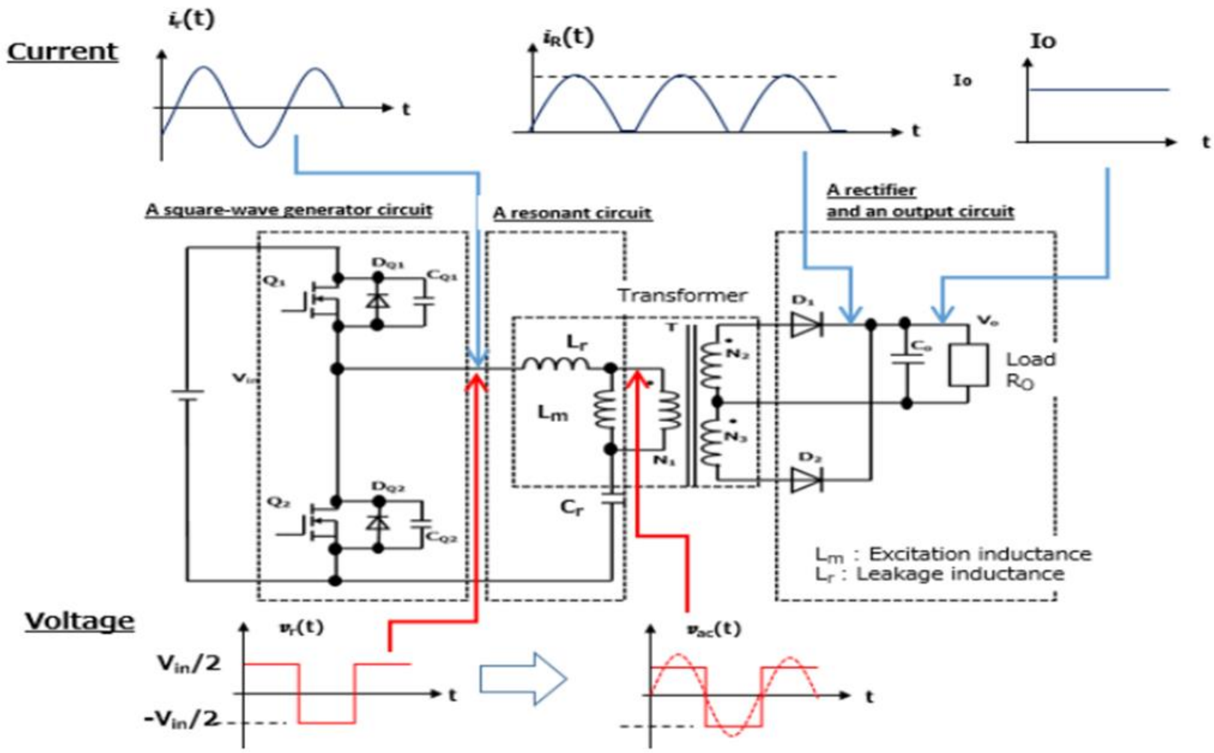


Equivalent Circuit of Power Delivery Operation

2. **Freewheeling operation:** It can occur following the power delivery operation only if the resonant current reaches the transformer magnetizing current, this only happens when fs>Lr, thus the primary current during the freewheeling operation will only change slightly, and can be approximated to be unchanged for simplicity. The equivalent circuits of the freewheeling operation in both halves of the switching cycle are shown in Figure below



Equivalent Circuit of Freewheeling Operation



- **Advantages:**

1. The current flowing in the primary side of the transformer flows in during the entire period, which ensures the full use of the magnetic core and avoids magnetic bias.

2. The voltage stress in the primary side of the transformer is low.

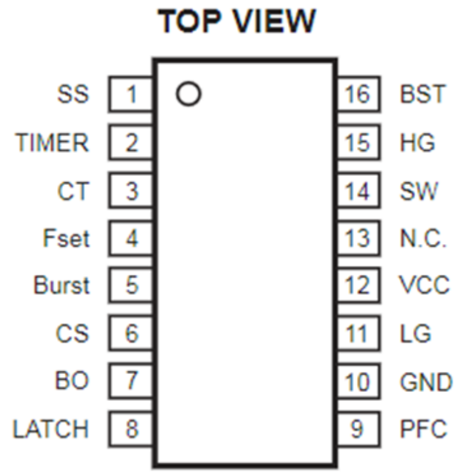
3. The structure is simple and the component costs are relatively low.

- **Disadvantages:**

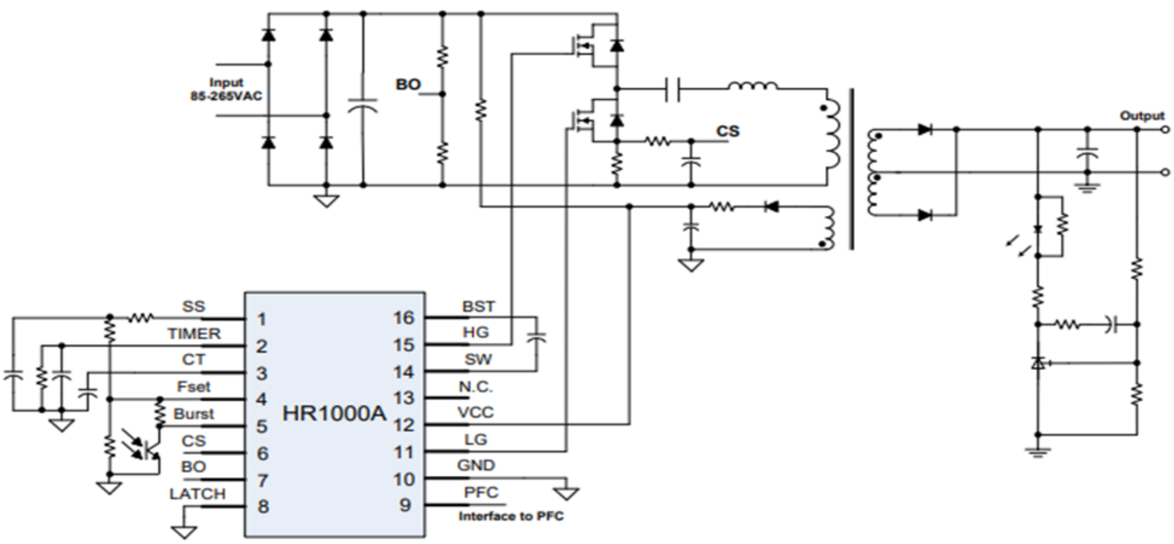
1. The current stress through the switches and primary side of the transformer is twice that of the full-bridge LLC resonant converter, and will cause large losses in the bridge capacitors.
2. The current ripples in the secondary side of the transformer are large, which may lead to voltage spikes and oscillations.
3. When the input voltage range is large, the switching frequency range needs to be increased accordingly. Thus, the potential high input will cause excessively high switching frequency and will intensify the adverse effects of the parasitic parameters, which may affect the converter system.
4. In order to adapt to a wide range of input voltages, the magnetizing inductor is required to be small, which causes increasing resonant current, so that the conduction loss and hysteresis loss would increase, hence reducing the converter efficiency.
5. With a wide input voltage range, if only selecting the power devices with high voltage tolerance, the conduction losses at the low-voltage state will also increase significantly, which will reduce the overall efficiency of the converter.

- **LLC Resonant Converter IC (HRA1000A)**

The HR1000A is a controller designed specifically for the resonant half-bridge topology. It provides two drive-signal channels that output complementary signals at a 50% duty cycle.



Pin Diagram



Typical Application Circuit

4.5 Basic Design Procedure of LED Driver

1. **Requirements and Specifications:** Define the operational requirements for your LED driver, including input voltage range, output voltage/current requirements, efficiency goals, dimming capabilities, and any specific safety standards that need to be met.

2. **LED Selection:** Choose the LEDs you'll be driving, considering their forward voltage, current rating, and the desired light output.

3. **Topology Selection:** Decide on the topology for your LED driver. Common non-isolated topologies include buck and boost converters.Choose the topology based on factors like input-output voltage difference, efficiency, and ease of control.

4. **Component Selection:** Select appropriate components for your chosen topology, including power semiconductors (MOSFETs or diodes),inductors, capacitors, and resistors. Ensure they can handle the required voltage and current levels.

5. **Calculation and Design:** Perform calculations to determine component values. This includes calculating the inductor value, capacitor values, switching frequency, and duty cycle based on the desired output current and voltage.

6. **Control Strategy:** Decide on the control strategy for your LED driver. This could involve pulse-width modulation (PWM) for dimming, current control loops, and voltage regulation.

7. **Feedback and Regulation:** Implement feedback loops to regulate the LED current or voltage. This could involve using current sense resistors, voltage feedback, and error amplifiers.

8. **PCB Layout:** Design the printed circuit board (PCB) layout, ensuring proper separation between high-voltage and low-voltage sections, minimizing noise, and providing proper heat sinking for components that generate heat.

9. **Testing and Simulation:** Simulate the designed circuit using software tools like SPICE to verify its performance. Once satisfied, build a prototype for testing. Measure efficiency, output voltage/current accuracy, and transient response.

10. **EMI/EMC Considerations:** Address electromagnetic interference (EMI) and electromagnetic compatibility (EMC) issues by implementing proper filtering, shielding, and grounding techniques to ensure your driver doesn't interfere with other electronic devices.

11. **Documentation:** Document your design thoroughly, including schematics, PCB layout, bill of materials (BOM), design calculations, and test results. This documentation will be valuable for future reference and for manufacturing.

4.6 Some Special Parts Design of LED Driver

4.6.1 Transformer Design:

Designing a ferrite core transformer for an isolated LED driver involves several steps to ensure efficient power transfer and safe operation. Below are the key design steps for creating such a transformer:

i. **Specifications and Requirements:** Define the input voltage range, output voltage, output current, efficiency targets, and any other requirements for your isolated LED driver.

ii. **Topology Selection:** Choose the appropriate topology for your LED driver. Common choices include flyback, forward, and push-pull configurations. Each topology has its own advantages and trade-offs.

iii. **Duty Cycle and Turns Ratio Calculation:** Determine the duty cycle (D) required for your chosen topology, which is the ratio of the transformer's ON time to the total switching period. Calculate the turns ratio (N=Np/Ns) based on the desired output voltage and input voltage, considering the voltage conversion ratio.

N = (Vout+Vf) / Vin-nom

iv. **Core Material Selection:** Choose a suitable ferrite core material based on factors like operating frequency, power level, saturation characteristics,and temperature requirements. Ferrite materials are categorized by their permeability, frequency range, and other magnetic properties.

v. **Core Design:** Determine the core dimensions (Ae: effective core area) based on the required power handling capability and the core material's saturation characteristics. Calculate the necessary core cross-sectional area to avoid core saturation.

Core Area (A) = Lp / (μ * N^2)

vi. **Wire Size:** Select appropriate wire gauges for each winding considering the current handling capacity and desired copper losses.Primary Wire Gauge (Dp) based on I out and Lp & the Secondary Wire Gauge (Ds) based on I out and Ls.

vii. **Inductance and Inductance Calculation:** Calculate the primary and secondary inductances based on the chosen operating frequency and core characteristics.This is important for determining the current ripple and ensuring proper energy transfer.

viii. **Primary Winding:** Wind the primary winding on the core, taking care to ensure proper insulation between turns and layers. The primary winding should be designed to handle the input voltage, current, and switching frequency.

Lp = (Vin-nom * N) / (f * Iout)

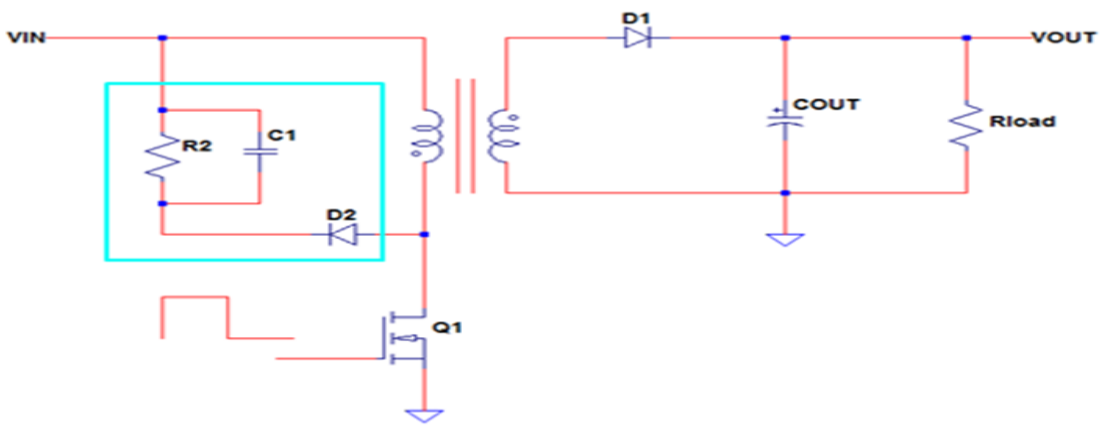
ix. **Secondary Winding:** Wind the secondary winding on the core, making sure to maintain the correct turns ratio. This winding is responsible for transferring energy to the output side.

Ls = (Vout * N) / (f * Iout)

x. **Auxiliary Windings and Feedback:** If necessary, design and wind any auxiliary windings for control, feedback, or other purposes. These could include secondary-side rectification, feedback winding, or output voltage sensing.

xi. **Insulation and Bobbin:** Insulate the windings properly to prevent short circuits between turns or layers. Use an appropriate bobbin or former to hold the windings in place and maintain proper spacing.

4.6.2 Snubber Circuit Design



A snubber circuit is often used to mitigate voltage spikes and ringing in switching circuits, like LED drivers. These voltage spikes and ringing can occur due to the fast switching of components like diodes and transistors. Here's a general outline of the steps to design a snubber circuit for an LED driver:

i. **Understand the Problem:** Before designing a snubber circuit, you need to understand the specific issues you're facing in your LED driver circuit. Identify the sources of voltage spikes and ringing, and determine their amplitude and frequency.

ii. **Select Snubber Components:** Choose the components for your snubber circuit. Typically, a snubber consists of a resistor and a capacitor connected in parallel or series across the switch (diode, transistor) that generates the spikes. The values of these components will depend on the characteristics of your LED driver circuit and the nature of the spikes.

iii. **Calculate Resistor Value:** The resistor's value is chosen to control the discharge rate of the capacitor. You'll need to calculate the resistor value based on the desired time constant (RC time constant) and the load characteristics. The resistor in the snubber circuit helps to control the discharge rate of the capacitor. It's usually chosen based on the desired time constant and the characteristics of the circuit.

Formula: R = T / (2 * C)

Where:R is the resistor value in ohms,T is the desired time constant in seconds (related to the speed of switching) & C is the capacitance of the snubber capacitor in farads.

iv. **Calculate Capacitor Value:** The capacitor's value is chosen to absorb energy from voltage spikes. Calculate the capacitor value to match the resonant frequency of the circuit to dampen the ringing effectively. You can use formulas that relate the capacitor value to the desired resonant frequency. The capacitor in the snubber circuit absorbs energy and helps reduce voltage spikes and ringing.

Formula: C = I * (dT/dV)

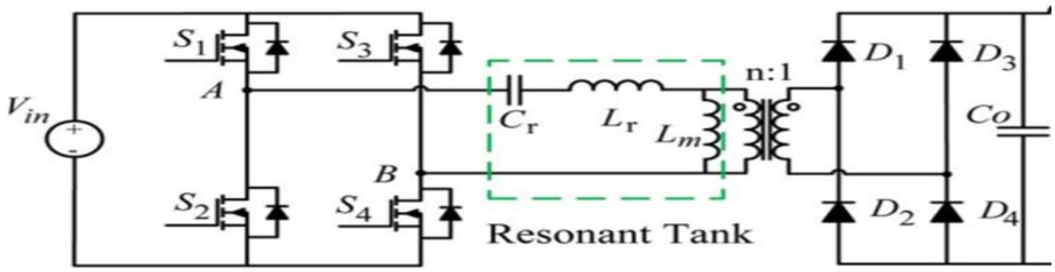
Where: C is the capacitor value in farads,I is the peak current through the snubber circuit in amperes & dT/dV is the rate of change of voltage with respect to time during the switching event.

v. **Diode Selection:** The diode used in the snubber circuit should be capable of handling the voltage and current requirements of the circuit. It should also have a fast switching speed to effectively clamp the voltage spikes

vi. **Damping Ratio and Resonant Frequency:** Calculate the damping ratio and resonant frequency of the snubber circuit. This will ensure that the snubber effectively absorbs the energy from voltage spikes and prevents excessive ringing.

vii. **Component Ratings:** Make sure the chosen resistor and capacitor are rated for the voltage and current levels in your LED driver circuit. It's also important to consider the power dissipation capability of the resistor.

4.6.3 Resonant Component Design (LLC)



Available Data: V_{in}=V_{in}(min)-V_{in}(max)

V_{out}, I_{out}, F_{sw}

We have to find out **- L_r, L_m, C_r**

Hints: **m= (L_m/L_r)** **m=6 (Typically to get min Loss, m=1 to 10)**

Z= sqrt(Lr/Cr) **ω_0=sqrt(1/L_r*C_r)**

L_r= Z/ω_0 **Cr = 1/(4*π^2*L_r*f_0^2)**

L_m=m*L_r

In the developed light sources we have used total 4 LED Drivers each of having the Flyback converter based LED Driver topology. Instead of using 4 drivers we can use a single LED Driver having 4 channel output but the designing will become much more difficult and the life of the driver become very much less,voltage regulation increases significantly and efficiency also reduces.So considering the reliability and long life and easy designing we have selected 4 drivers and and used Flyback topology instead of using a single driver and LLC resonant converter topology.For each color we have used a separate driver to control the current level to control the contribution of illumination level to maintain the proper ratios of different colors what we have used here.

CHAPTER-5 LITERATURE REVIEW

The energy efficiency of LED lamps is now being quickly improved by lighting technology, with the focus on reducing energy consumption and emissions of CO2 equivalents [1]. The effects of the existing luminaires on color perception [2] and human health [3,4] and well-being [5] are generally not taken into account in this development. Numerous scholars have claimed that in order to give consumers a comfortable atmosphere, urban and architectural lighting should consider both the quality and amount of light [6,7,8]. Additionally, a safe environment for pedestrians and drivers alike depends on the spectral distribution of the light sources since it promotes accurate color perception and hue discrimination [9,10]. Most importantly the proper color quality is must specially in medical sectors where critical tasks are being performed .

People are doing research on tunable CCT light source design for various purposes such as office working people having night shifts.These people suffer from the irregular human circadian rhythm due to irregular secretion of melatonin hormone[11-12]

Nowadays, the Color Rendering Index (CRI) is the most widespread metric for determining the hue deviation of any light source. This concept, presented in 1974 [13] and subsequently recognized by the Commission internationale de l'eclairage (CIE) [14], was proposed as a method for quantifying the color performance attained by fluorescent lamps. Based on the deviation of eight color samples in the CIE diagram, CRI uses a variable light source reference with a theoretically perfect rendition to determine the performance of the lamp under study. However, some inaccuracies can be observed in the CRI calculation, mostly in the non-uniform color distribution of the color space [15] the low saturation of the color sample selected for evaluating the hue deviation [16] and the choice of the light source of reference [17]. Considering these limitations, this metric was updated in 1999 to include six new illuminants [18], although it did not provide a satisfactory description of the color rendition of LED lamps.

Subsequently, in 2010, the Color Quality Scale (CQS) [19] was proposed in order to provide an accurate calculation of color rendition for LED lamps. This new concept establishes 15 new color samples with a higher saturation than in previous metrics, an updated color space based on a CIE lab and a new Chromatic Adaptation Transform (CAT) recommended by the Color Measurement Committee (CMC), CMCCAT2000. This metric arose from the need to answer several issues related to color performance, among them the higher levels of naturalness and attractiveness provided by LED lamps in comparison with halogen light sources, despite the CRI score suggesting otherwise [20].

In recent years to resolve the issues of the workplace, timings and culture have been changed significantly due to digitization and globalization Employees and students are generally confined to watching the digital display within a large building for the most of the timings of a day and even after sunshine hours. In this context, most of the recent studies state that natural light has a positive effect on the improvement of health and well-being of human beings[21-22].

One of the most recent procedures for providing a full description of the color perception allowed by a light source is TM-30-20, developed by the Illuminating Engineering Society (IES) [23]. This procedure compares the results for 99 samples from the CIE color space and establishes a continuous illuminant reference which varies depending on the color temperature of the light source under study. IES is currently promoting the use of this new procedure among luminaire manufacturers [24]. After the first proposal of this metric, TM-30-15 [25], in 2015 and prior to the previous update in 2018, the CIE developed the Color Fidelity Index (CIE 2017) [26] based on an optimized version of the color sample proposed by the IES aiming to improve the results obtained by the CRI. This new metric does not address an extensive analysis as in the case of TM-30-20, although it provides a more accurate calculation of color fidelity.

The results of this study conclude that the current color rendition metrics do not meet the criteria for color preference but can be predictable according to calculation models based on the metrics defined by TM-30-20; the Fidelity Index (R_f) and the Gamut Index (R_g).

The other focus of this research is also to develop a driver circuit which drives the LED strings with a minimum drive voltage leading to high efficiency across the strings and reduction of unwanted power losses in the current controller circuits while maintaining good current regulation in the strings.

In recent years, LEDs are being introduced in liquid crystal displays (LCDs) , backlight, display panels, signage, streetlights, automobiles, traffic lights, and general-purpose lighting due to advancement in LED technology and reduced energy consumption [27]-[32].In comparison to traditional light sources such as incandescent lamps and cold cathode fluorescent lamps (CCFLs), LEDs have a longer lifetime, in the range of 80,000 – 100,000 hours [3]-[4].The absence of mercury makes LEDs environmentally friendly as they can be disposed of safely [3]-[4]. Additionally, LEDs have wider color gamut, higher luminance, and smooth-dimming properties [3]-[8].

An approach was discussed in several articles to increase the CRI with CCT changing lighting system is the color mixing of lights based on the Grassmann's law of additive color [34], which states that, two or more color source can be mixed to generate another blended color source. In some previous studies the variable white light source is generated by the mixing of red-green-blue (R-G-B) sources [35-37] and red-green-blue-amber (R-G-B-A) sources [38-39] are demonstrated. This type of system has CRI between 80 and 90 but the chromaticity shifts due to dimming and temperature variation is noticeable. It is reported that the chromaticity shift in phosphor coated white light is less compared to color mixing of monochromatic light sources when a similar dimming method is applied to it [40]. Tunable CCT light source using two phosphor coated white lights is reported in previous articles [41-43], where a warm white light source with low CCT is mixed with a cool white light source with higher CCT to generate a daylight responsive lighting system.. Though the control algorithm for that system is less complicated, but blended CCT lies between the warm white source's CCT and cool white source's CCT and there is no significant difference in CRI. Another wide range tunable CCT (2500 K-12500 K) and illuminance control lighting system by mixing of cool white - blue and cool white - red is reported [44] to generate CCTs above 6500 K and below 6500 K respectively with CRI value near 90. In this system the co-ordinate of blended CCT lies on the cool white and blue joining locus and cool white and red joining locus. So the deviation of blended CCT point from the Planckian locus is noticeable, hence Duv value increases. Color mixing using warm white-cyan-red sources for museum lighting is reported [45] where both CRI and R9 values are greater than 90. But it is applicable for very small CCT varying range (around 200 K). A simulated work is reported using red-green-blue-cyan-amber-white (RGB-CAW), RGB-amber and RGB-white LEDs [46], where tunable CCT range is 3200 K to 7500 K and maximum CRI 97 is achieved for RGB-CAW luminaire, but this system is hard to realize in practical application and the system cost will be very high as it uses six colors of LEDs. Another simulation based work is proposed with very high CRI 95 and luminous efficacy of 344 Im/W for a tunable CCT range of 2020K to 7929 K; where blue-green-yellow-red color components are used [47] and a generic algorithm with a penalty function is proposed. In this system, used blue-green-yellow-red chips have very high luminous efficacy; so that a high efficacy is achieved in blended light sources. Researchers I have been working with five component and six component color mixing methodology [48-49] and achieved the CRI above 90 but the electronic circuit of such a system is very difficult and hard to implement in practice.

LEDs are current-driven devices, i.e. their brightness is proportional to its current [50]-[54]. Due to limitations in LEDs packaging, the output power of each individual LED is less than 20 W [50]. Therefore, in order to obtain the same luminance as other traditional light sources, many LEDs have to be connected in parallel or series. But there is a limit on the number of LEDs that can be in 2 series due to limitations on its drive voltage. Similarly, the drawback of LED strings connected in parallel is its current sharing between the strings leading to lower lifetime for the LEDs due to its exponential voltage-current relationship [50].

There are several methods of driving LEDs connected in parallel. The straightforward approach is to have individual constant current drivers for each string in parallel as shown in Fig. 5.1 [54]**.** The constant current driver can either be a SMPC or linear voltage regulator. A linear constant current driver is cost effective but it suffers from power losses in its series-pass transistors [33]. However, SMPC constant current drivers are much more efficient but they require storage devices such as capacitors, and inductors for voltage conversion leading to higher parts count and increased cost. Moreover, this approach of employing individual constant current drivers for each LED string in parallel is not cost effective for drivers that have a large number of LED strings in parallel as in LCD backlight, display panel, and general-purpose lighting applications.

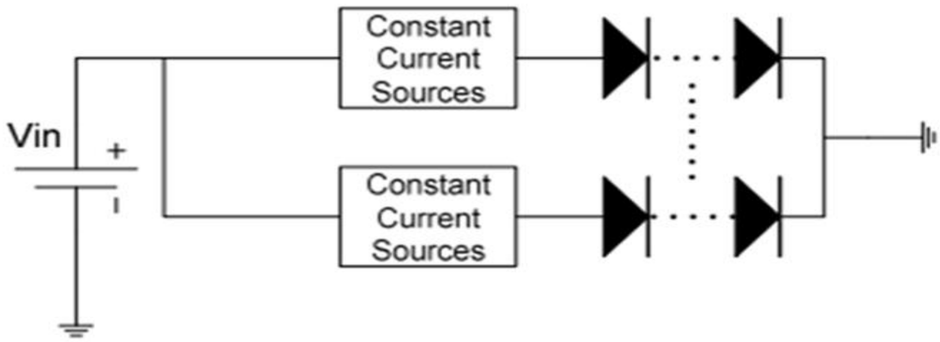


Fig-5.1 A LED driver with individual constant current driver for each LED strings

For driving LEDs strings in parallel, a different approach is usually employed which uses current controllers for each string in parallel for maintaining the current in the strings and the drive 3 voltage is provided by the SMPC as shown in Fig. 5.2. In this implementation, the output voltage of the driver is set at its worst-case by the feedback voltage in order to maintain all the current controllers in regulation [55]-[56]. Therefore, in order to improve the efficiency of the output LED strings in this approach, matched forward voltage LEDs are used which adds to the cost of the driver.

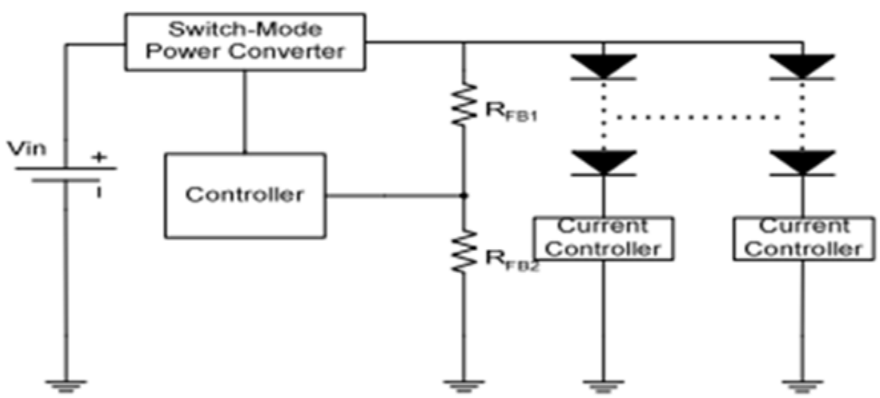
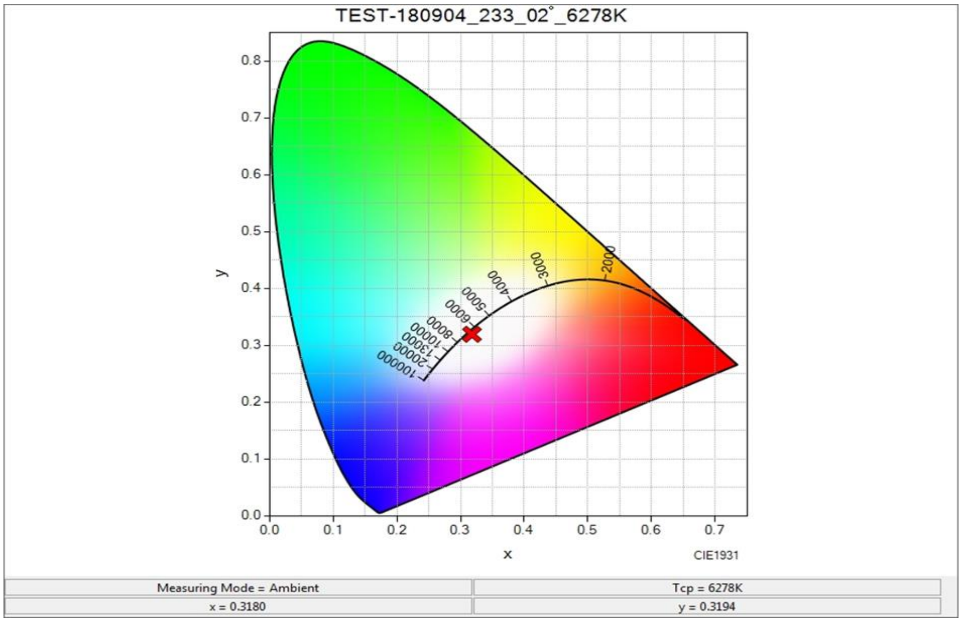


Fig-5.2 A LED driver with SMPC using individual current controllers for each LED string in parallel.

CHAPTER-6 MATHEMATICAL FORMULATION:



Here four light sources of different CCT and lower CRI(70-80) namely warm white,cool white,green and blue are mixed together to generate proper CCT and high CRI.The chromaticity coordinate of white(mixed of warm white and cool white) as W(Xw,Yw),green as G(Xg,Yg) and blue as B(Xb,Yb) light sources are shown on CIE 1931 chromaticity diagram.

The required chromaticity coordinate for the target CCT is T(Xr,Yr) which will definitely be an arbitrary point over the Planckian locus.The straight line of the connecting points W(Xw,Yw) and T(Xr,Yr) will intercept the straight line of the connecting points B()Xb,Yb) and G(Xg,Yg) at point(intercepting point) P(Xp,Yp).So as per the requirement of CCT we will choose the type and the amount of light to be mixed.The Generalized mathematical deviation of three LED color mixing is described in [40]

The chromaticity coordinate of any CCT point $T_c(X_c,Y_c)$,which is on the planckian locus and generated by blackbody radiation can be derived by the following equations for a CCT(T_c)

For CCT of 2222K to 4000K

$$Xr = -0.2661239*10/Tc^3 - 0.2343580*10/Tc^2 + 0.8776956*10/Tc + 0.179910 \quad (1)$$

$$Yr = -0.9549476*Xr^3 - 1.37418593*Xr^2 + 2.09137015*Xr - 0.16748867 \quad (2)$$

For CCT of 4000K to 25000K

$$Xr = -3.0258469*10/Tc^3 + 2.1070379*10/Tc^2 + 0.2226347*10/Tc + 0.240390 \quad (3)$$

$$Yr = 3.0817580*Xr^3 - 5.87338670*Xr^2 + 3.7511299*Xr - 0.37001483 \quad (4)$$

Here we need daylight like CCT so we will choose equations 3 and 4 for our calculations. The slope of WT line and WP lines are the same as the points W,P,T are in the same straight line.

Hence, $$Yp = (Yr-Yw)/(Xr-Xw)*(Xp-Xw) + Yw \quad (5)$$

The slope of the PB line is the same as the slope of the GB line as the points G,P,B all lie on the same straight line.Hence,

$$Yp = (Yg-Yb)/(Xg-Xb)*(Xp-Xb) + Yb \quad (6)$$

The point P may be any point on the GB line.The value of Xm and Ym depend on the required CCT value and point T(Xr,Yr).Depending upon the required CCT,the blue-green blending ratio will change,hence the blending point P(Xp,Yp) will also change.The point P also lies on the line connected between green-blue source points.

From the grassmann's law of color mixing it is found that the vertices of blended color can be derived by the linear weighted sums of the chromaticity coordinates of two mixing light sources.Hence,

$$Xp = Xb*Wc1 + Xg*Wc2 \text{ and } Yp = Yb*Wc1 + Yg*Wc2 \quad (7)$$

Where Wc1 and Wc2 are the weighted coefficients and can be given by the equations

$$Wc1 = A1/B1 \qquad Wc2 = A2/B2 \quad (8)$$

A1= Yb/yb A2= Yg/yg B1= Yb/yb + Yg/yg B2 = Yb/yb + Yg/yg

Yb and Yg are the luminance values of blue and green light sources respectively.Grassmann's law of color mixing stated that**,**

$$Wc1 + Wc2 = 1 \quad (9)$$

When the distance between the light source and object is fixed,reflectance of surrounding is fixed,transmission of the medium is constant then the luminous parameter Y is equivalent to illuminance E.

To achieve the point P,duty cycle of the blue sources is DCb and green source is DCg.Hence the individual illuminance of blue and green source to achieve point P is given by

$$Eb = Ebm*DCb \text{ and } Eg = Egm*DCg \quad (10)$$

Where Ebm and Egm is the maximum illuminance of blue and green sources.

The maximum illuminance of point P(Xp,Yp) is Epm can be derived by the linear combination of blue and green sources when the maximum illuminance of the blue and green source is fixed

$$Epm = Eb + Eg \text{ or } Epm = Ebm*DCb + Egm*DCg \quad (11)$$

And

$$Emm = Ebm + Lbm*(Egm - Ebm)/Lbg$$

Where Lbp is the linear distance between B(Xb,Yb) and P(Xp,Yp) points and Lbg is the linear distance between B(Xb,Yb) and G(Xg,Yg) and we already know how to find the distance between two points.

Illuminance of warm white light source at required CCT point is given by

$$Ew = Ewm*DCw \text{ and } Em = Epm*DCm$$

So to get required CCT and required illuminance level we have to take each light source in proper ratio.

We have to maintain Ew : Eg : Eb ratio to get proper CCT and illuminance level at that CCT point.

CHAPTER-7 INSTRUMENTS USED IN THE SYSTEM:

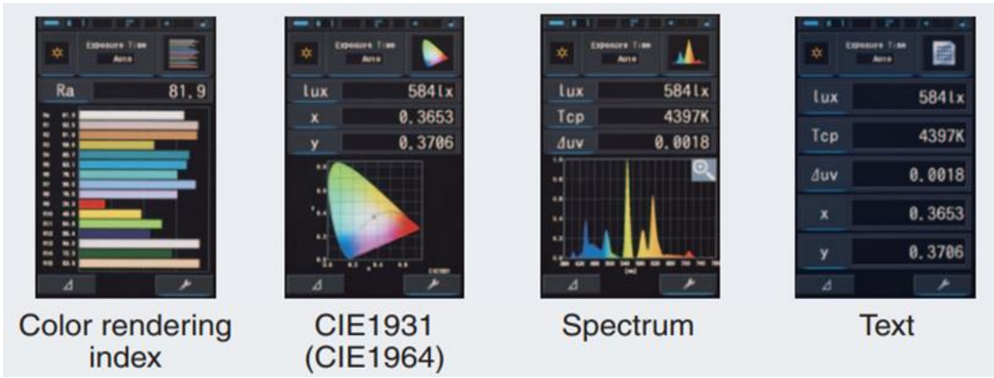
The developed system consists of 4 LED luminaire and each luminaire has a string of Cool White,Warm White,Green and Blue LEDs and the LED Drivers arranged in a single luminaire.To get the photometric and colorimetric data we have used CRI Meter and to get lumen output and intensity distribution data we have used Goniophotometer. To get the proper dimension of the systems in laboratory and also of the system developed.

7.1 CRI Meter

The CL-70F CRI Illuminance Meter is an entry-level solution for the measurement and evaluation of the illuminance, color temperature, and color rendering index (CRI) of various illumination sources such as LEDs and fluorescent lamps. It is most commonly used in restaurants, museums, studios, and theaters for accurate light measurements. Its high-resolution CMOS sensor captures and displays the spectral power distribution of current and future generation light sources including LEDs, HID, Halogen, and OLEDs providing unparalleled color measurement accuracy.It is made by Konica Minolta Company.

The CL-70F, a cost-effective spectrometer based illuminance meter, uses an accumulation type sensor to measure electronic flash. CL-70F can display color data for accurate CRI, color temperature and spectral color precision. The electronic flash can be measured with a PC cord connection or in cordless mode.

CRI Meter (CL-70F)



CRI Meter Output

7.2 Goniophotometer :

LSG-6000 goniophotometer manufacturer is LISUN, it can measure all types of lighting sources, LED, Plant Lighting or HID luminaires such as indoor and outdoor luminaires, roadway luminaires, street lamps, flood lights and other kinds of luminaires. It measures Luminous Intensity Data, Photometric Data, Luminous Intensity Distribution, Zonal Luminous Flux, Luminaries Efficiency, Luminance Distribution(Option), Coefficient Of Utilization, Luminance Limitation Curves Glare, Maximum Ratio of Distance to Height, Equal Illuminance Diagrams, Curves of Luminaires VS Lighting Area, Isocandela Diagrams and electrical parameters(voltage,current,power and power factor) etc.

The Luminaire rotates around under test with the vertical axis and also in horizontal axis. In vertical axis total 180 degree of rotation with each step of 5 degree the measurement taken and in horizontal axis total 360 degree of rotation with each step of 1 degree the measurement is taken.

Goniophotometer

A Goniophotometer can test all of the above luminaires.

Goniophotometer Set Up

7.3 Bosch GLM 40 Professional Laser Measure:

- **All relevant functions in a compact design**
  - Distance measurement, area calculation, volume calculation – all intuitive to use
  - Illuminated, three-line display maximizes readability
  - Memory function enables easy access to the last ten measurements
  - Robust, shockproof housing with IP54 protection class (splash and dust protection)
  - Reliable measuring results in all circumstances, proven by ISO certification

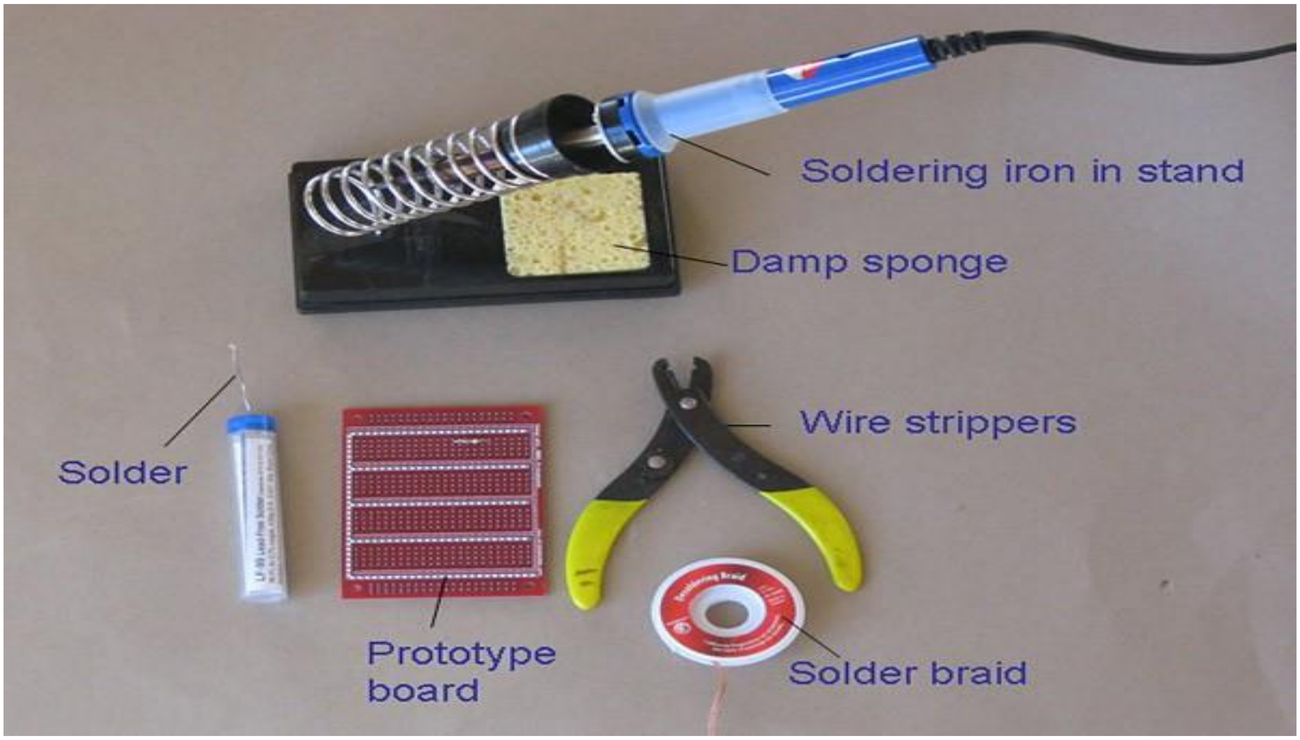
- **Technical Data**

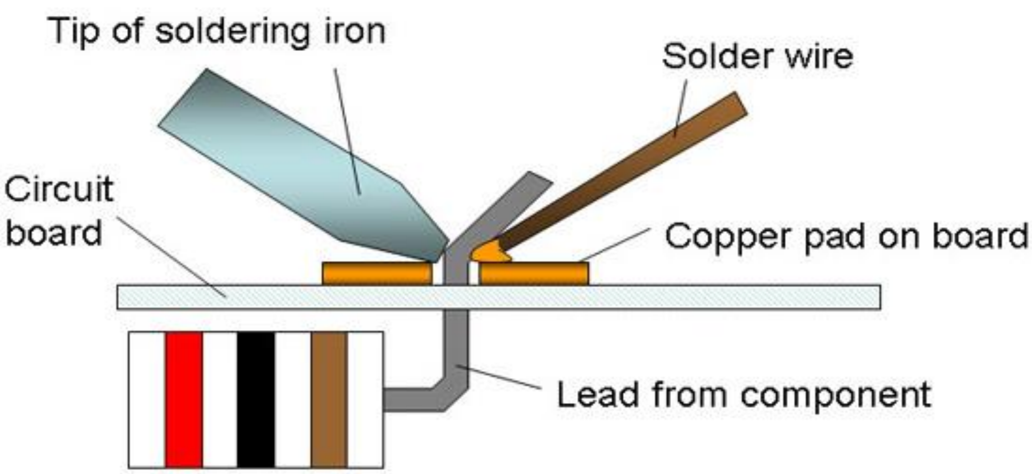
Laser diode	**635 nm, < 1 mW**
Measurement range	**0.15mm – 40m**
Laser class	**2**
Measurement accuracy	**typical +/- 1.5 mm**
Measurement time	**typical < 0.5 s**
Measurement time	**max. 4 s**
Power supply	**2 x 1.5 V LR03 (AAA)**
Automatic deactivation	**5 min.**
Weight, approx.	**0,09 kg**

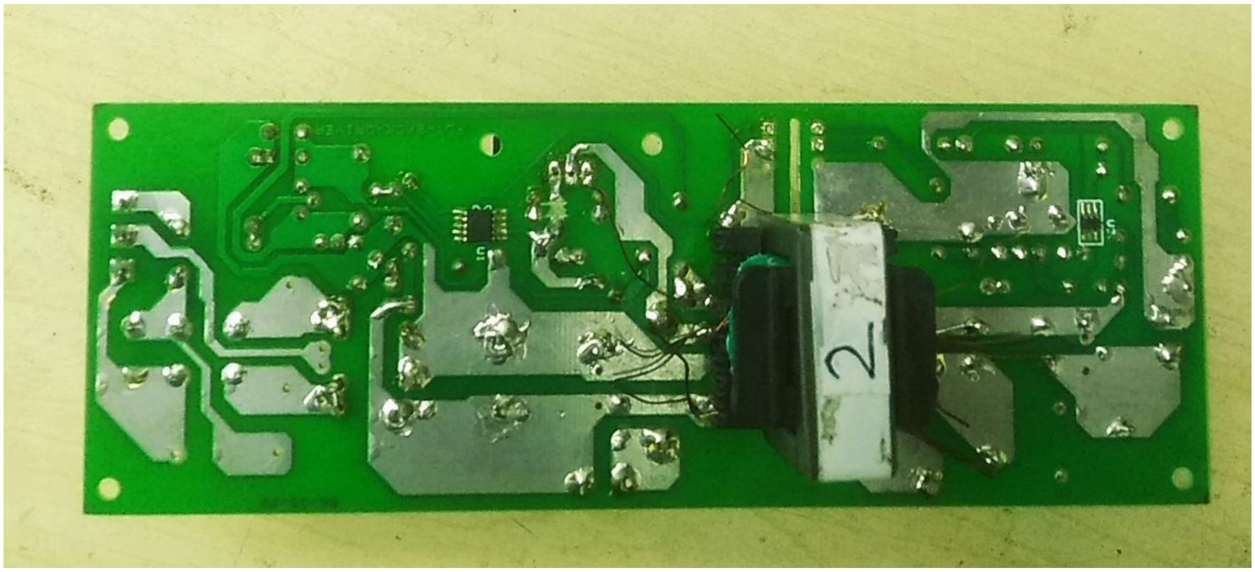
Units of measurement m/cm, ft/inch	
Memory capacity (values)	**10**
Battery lifetime, individual measurements, approx	**5.000**
Dust and splash protection	**IP 54**

7.4 Soldering Iron and Solder wire:

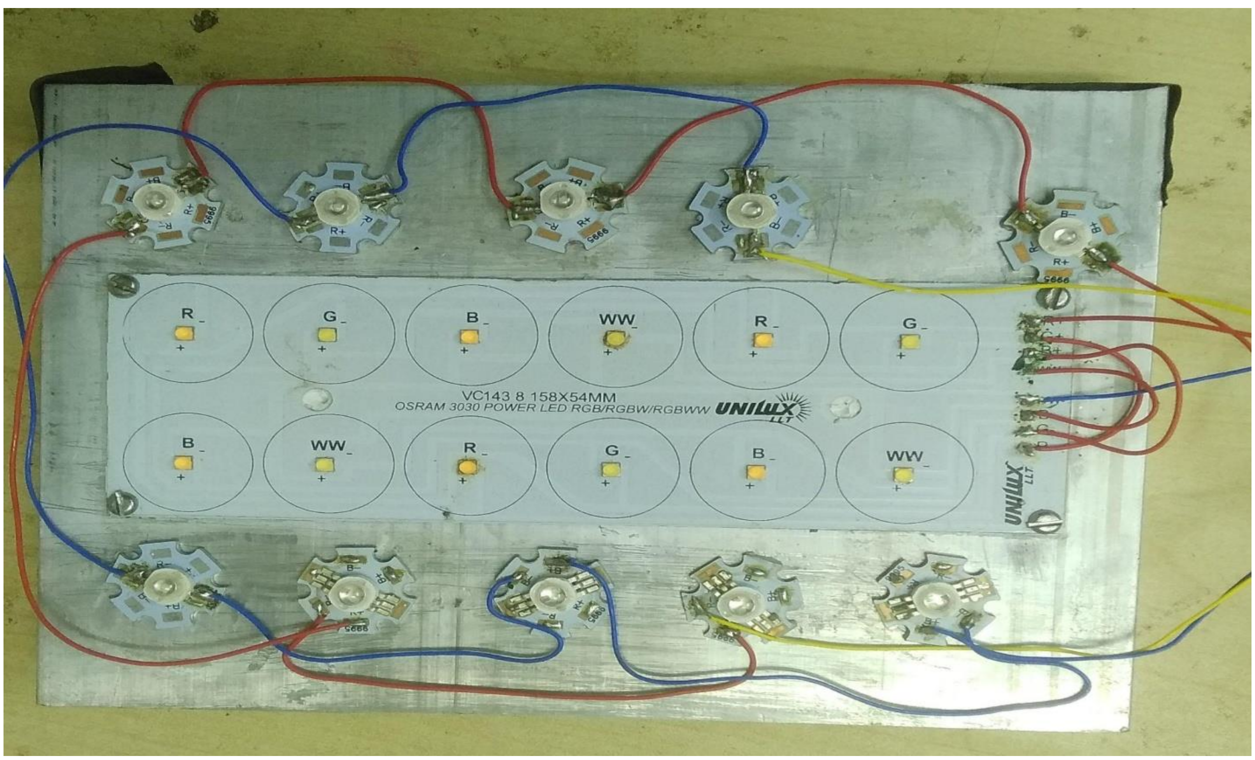
For designing the LED Driver we have to place the components in the PCB.We need to connect the LEDs which are used here that connection will be done by soldering .To connect the component we have to solder by soldering iron and solder wire along with some other equipment such as soldering paste,desoldering pump etc.


Soldering iron in stand
Damp sponge
Solder
Wire strippers
Prototype board
Solder braid


Tip of soldering iron
Solder wire
Circuit board
Copper pad on board
Lead from component



Solder Side of LED Driver



Connection of LEDs by Soldering

CHAPTER-8 EFFECTIVE LIGHTING DESIGN CALCULATION METHOD

A well-designed lighting system provides just the right amount of light for its intended application: less lumens yield poor performance, but more lumens represent wasted energy. Like in any building system design, the optimal capacity can only be specified with an adequate calculation procedure. Lighting designers use the photometric data of proposed fixtures as a starting point. For the calculation procedure they consider the project's location, indoor or outdoor, as well as environmental conditions like temperature and dirt.

The purpose of lighting calculation is to reach a suitable illuminance level for the intended application. The concept of illuminance describes lighting delivered per unit of area, and it is typically measured in foot-candles (lumens per square foot) or lux (lumens per square meter). In the case of New York City, meeting the lighting efficacy requirements of the NYC Energy Conservation Code is also important.

Illuminance levels for each location are not arbitrary; they are established by industry organizations such as IESNA (Illuminating Engineering Society of North America). When specifying a lighting system, design engineers aim for the illuminance values established in the IESNA Lighting Handbook. Achieving the exact specified values is not feasible, but a lighting design is satisfactory if the variation is slight.

Lighting calculations can be carried out manually, but this approach demands considerable man-hours and is impractical in modern building design. A more effective approach is using automated software calculations, allowing the lighting designer to focus on the best decisions, while a computer handles repetitive tasks.

The lighting design specialization is available for professionals from different backgrounds. For example, architects, electrical engineers and interior designers all have a knowledge base that is suitable to complement lighting design.

8.1 The Lumen Method: Basic Lighting Calculations

The lumen method provides a simple hand calculation approach to estimate the illumination achieved with a proposed lighting distribution. The method becomes impractical for complex room geometries or very large projects that are split into multiple areas. It can be summarized in the following steps:

i. **Calculate the Room Cavity Ratio (RCR)**

The RCR describes the ratio of vertical area to horizontal area in a room. The RCR formula varies depending on room geometry.

ii. **Obtain surface reflectances**

The reflectance is the fraction of light reflected from a surface, and it is strongly influenced by texture and color. Reflectance values are required for ceilings, walls and floors.

iii. **Obtain photometric data**

When you purchase a lighting product, its specifications include total lighting output and its spatial distribution. This is fundamental information for lighting calculation procedures.

iv. **Determine the Coefficient of Utilization (CU)**

Based on the RCR and surface reflectances, it is possible to determine the CU, which indicates how efficiently the lighting output is delivered to the working plane. The CU is obtained from tables in the IESNA Lighting Handbook, and it is also known as Utilization Factor (UF).

v. **Calculate the Maintenance Factor (MF)**

The maintenance factor accounts for lighting fixture degradation over time, as well as dirt accumulation. Deterioration and dirt reduce the lighting output, and illuminance falls below the specified level over time if their effect is not accounted for.

vi. **Use the Lumen Method Formula**

There are two ways to apply the formula. It can be used to calculate the number of luminaires required to reach a given illuminance value, or vice versa - calculating the illuminance that results from a given number of fixtures.

The lumen method formula is provided below:

$$N = \frac{E \times A}{n \times F \times CU \times MF}$$

Where,

N = Number of luminaires

E = Required illuminance

n = Lamps per luminaire

F = Lumen output per lamp

CU = Coefficient of utilization

MF = Maintenance factor

The advantage of the lumen method is simplicity, only requiring basic room data and luminaire data. However, it only provides an average illuminance value that does not reflect variations for different parts of the room. In other words, it is impossible to predict if there are excessively illuminated areas or dark spots.

- **Flowchart of manual calculations**

1. Start
2. Define Project Requirements
3. Determine Illuminance Levels
4. Select Appropriate Lighting Standard
5. Calculate Room/Area Size
6. Identify Room/Area Geometry
7. Select Lighting Fixtures
8. Calculate Initial Lumens Required
9. Check Luminaire Efficiency
10. Calculate Total Lumens Required
11. Determine Lamp Type and Wattage

12. Calculate Number of Fixtures Required
13. Layout Fixture Locations
14. Consider Fixture Spacing and Arrangement
15. Evaluate Light Distribution
16. Calculate Maintenance Factors
17. Calculate Coefficient of Utilization
18. Calculate Luminance Levels
19. Assess Glare and Uniformity
20. Adjust Fixture Positions and Types if Necessary
21. Finalize Lighting Design
22. Document Design (Drawings, Reports, Specifications)
23. Review and Verify Compliance with Local Codes
24. End

The manual lumen method of illumination calculation has several drawbacks, which have led to its declining popularity in favour of more advanced lighting design methods. Some of the key drawbacks include:

i. **Simplistic Approach:** The lumen method is a simplistic method that assumes uniform illumination throughout the space. In reality, most spaces have non-uniform lighting requirements due to various factors like architectural features, task requirements, and the placement of fixtures. This method may result in over-illuminating some areas and under-illuminating others.

ii. **Inaccuracy:** The lumen method relies on various assumptions and simplifications, making it less accurate for complex lighting scenarios. It does not consider factors such as reflective surfaces, surface colors, or the presence of obstructions, which can significantly affect the actual lighting levels in a space.

iii. **Lack of Flexibility:** The lumen method does not easily accommodate changes in lighting design or modifications to the space. If adjustments are needed, the entire calculation process may have to be repeated, which can be time-consuming and impractical.

iv. **Not Suitable for Complex Spaces:** The lumen method is best suited for simple, open spaces with regular layouts. In complex spaces with irregular shapes or multiple zones requiring different lighting levels, it may not provide an accurate or efficient lighting solution.

v. **Ignore Light Distribution Characteristics:** The lumen method does not consider the specific distribution characteristics of different lighting fixtures. Modern lighting design often involves selecting fixtures with specific beam angles and distributions to achieve the desired lighting effects, which the lumen method does not account for.

vi. **Energy Inefficiency:** Due to its uniform lighting assumption, the lumen method can result in over-lighting, leading to unnecessary energy consumption and increased operating costs.

In summary, while the lumen method was a valuable tool for simpler lighting design tasks in the past, it has several drawbacks when applied to modern, complex lighting design projects. Designers are now turning to more advanced methods and tools that provide greater accuracy, flexibility, and energy efficiency in achieving the desired lighting outcomes which can be provided by the Lighting designing software like Dialux, Relux etc.

8.1 Dialux:

DIAlux is one of the leading software on lighting design, used to calculate, and visualize indoor/outdoor lights, which is a time-saving software when compared to the manual calculation.

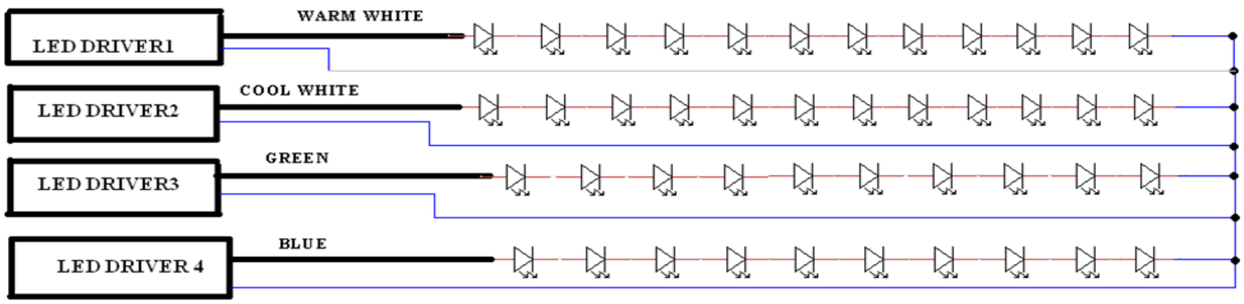
- **Flowchart for software simulation**

1. Start
2. Define Project Parameters (Room size, shape, purpose, etc.)
3. Import (Autocad file) or Create Room Geometry
4. Add Windows and Skylights (If applicable)
5. Define Surface Materials (walls, ceilings, floors)
6. Select Lighting Fixtures (from the DIALux fixture database)
7. Position and Orient Fixtures in the Room
8. Configure Fixture Properties (Wattage, Color Temperature, etc.)
9. Set Lighting Controls (Switches, Dimmers, Sensors, etc.)
10. Perform Lighting Calculation
11. Evaluate Illuminance Levels and Uniformity
12. Analyze Daylight Integration (If applicable)
13. Check Compliance with Lighting Standards and Regulations
14. Optimize Lighting Design (Adjust fixture placement, properties, etc.)
15. Generate 3D Visualizations and Renderings
16. Create Lighting Design Report
17. Export Documentation and Reports (PDF, DWG, etc.)
18. End

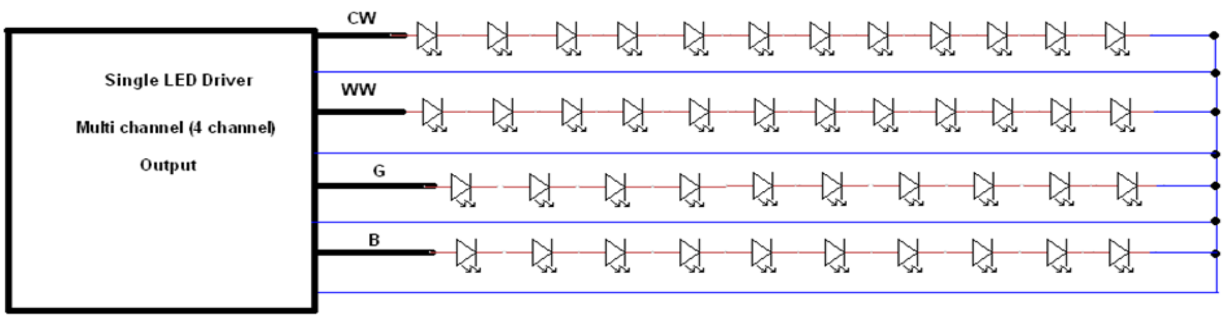
CHAPTER-9 IMPLEMENTATION OF THE PROPOSED SYSTEM

9.1 Block diagram

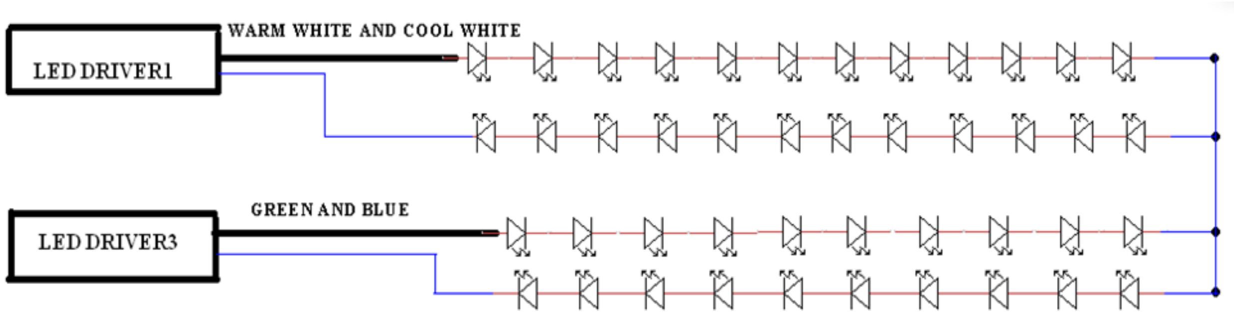
9.1.1 Block diagram 1 (4 separate LED Driver):



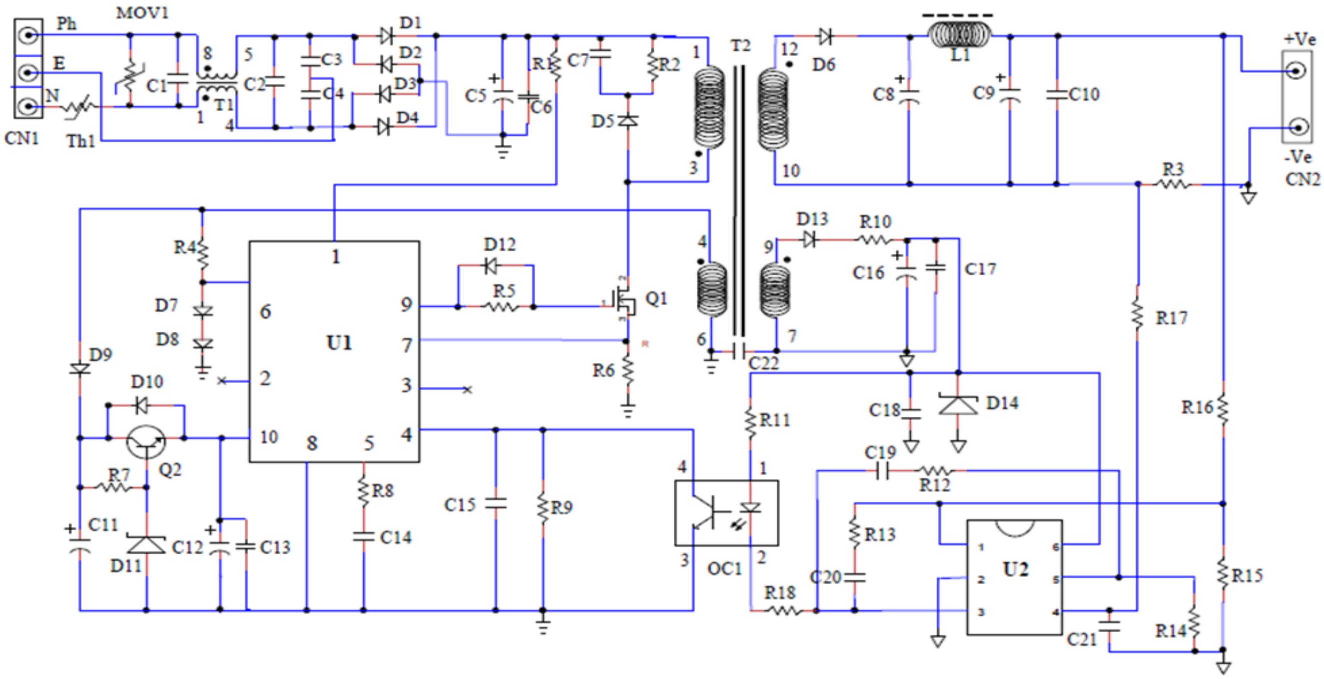
9.1.2 Block Diagram 2 (Single led driver 4 channel output)



9.1.3 Block Diagram 3 (2 led driver, 1 for WW and CW another for G and B)

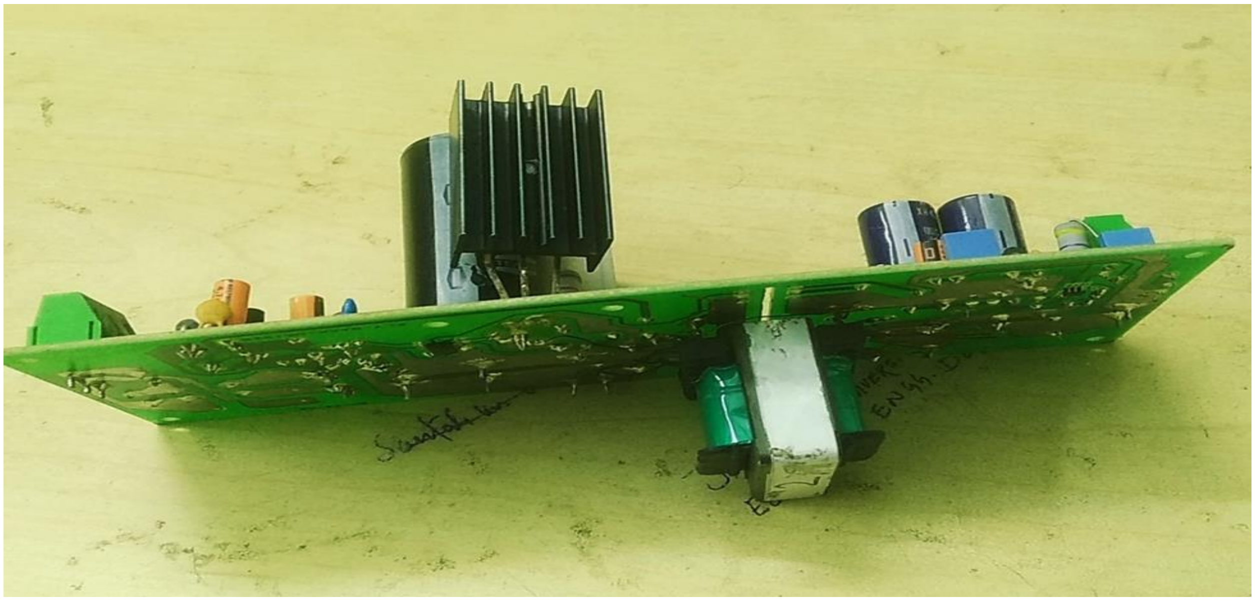


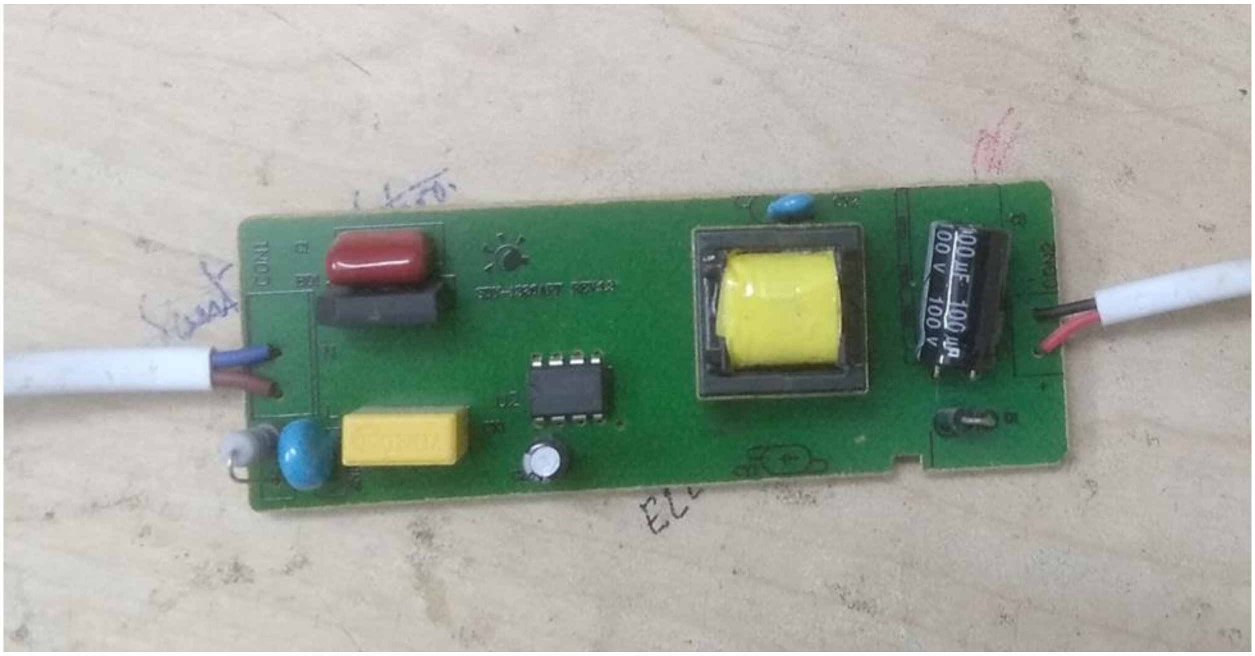
9.2 Circuit Diagram of LED Driver



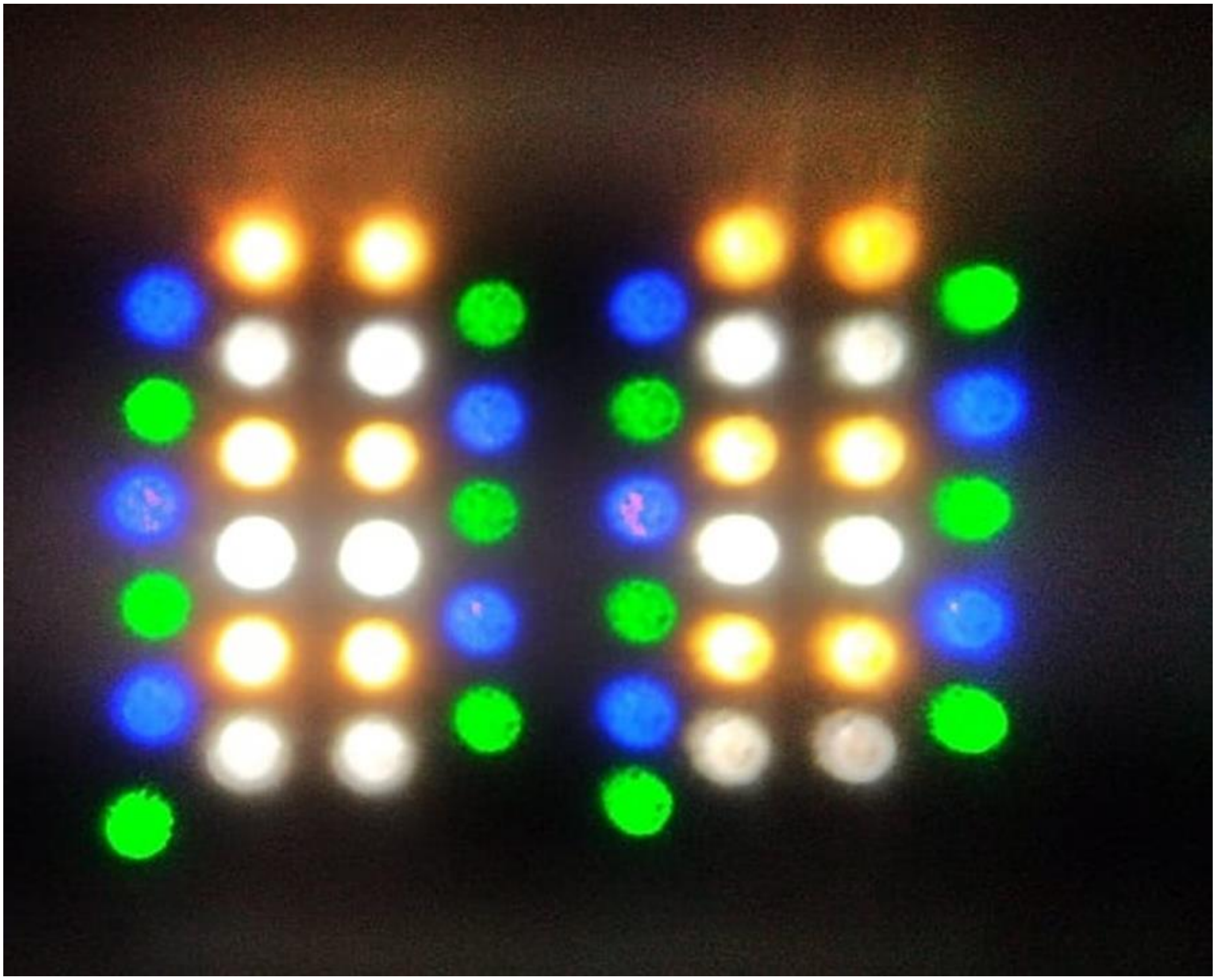
9.3 Developed system

9.3.1 LED Driver:





9.3.2 LED arrangement:

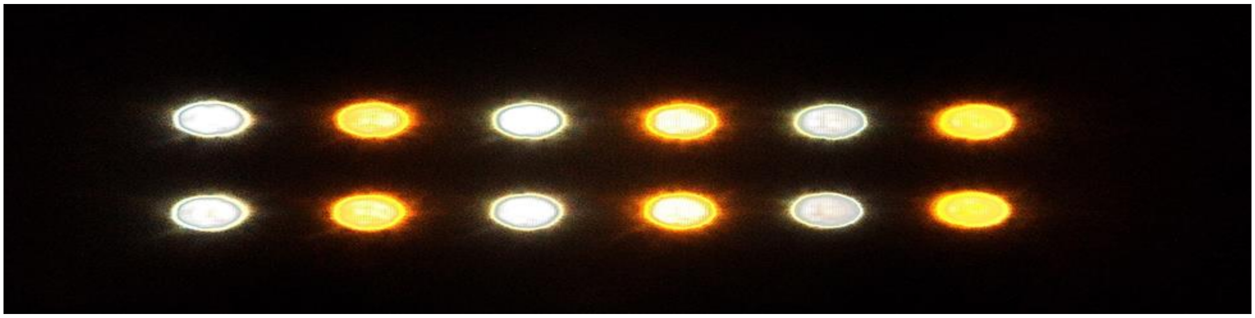


CHAPTER-10 EVALUATION AND TESTING

In this chapter, we start a thorough investigation of the assessment and testing techniques used to rate the high-color-quality light source. The results of this evaluation will not only confirm the effectiveness of our design but will also add to a larger discussion on lighting technology by providing new information and prospective developments that may be useful for a range of applications, from architectural lighting to the creative arts and also the places where critical tasks are being performed specially in medical sectors.

10.1 Laboratory Experiments with the developed light sources

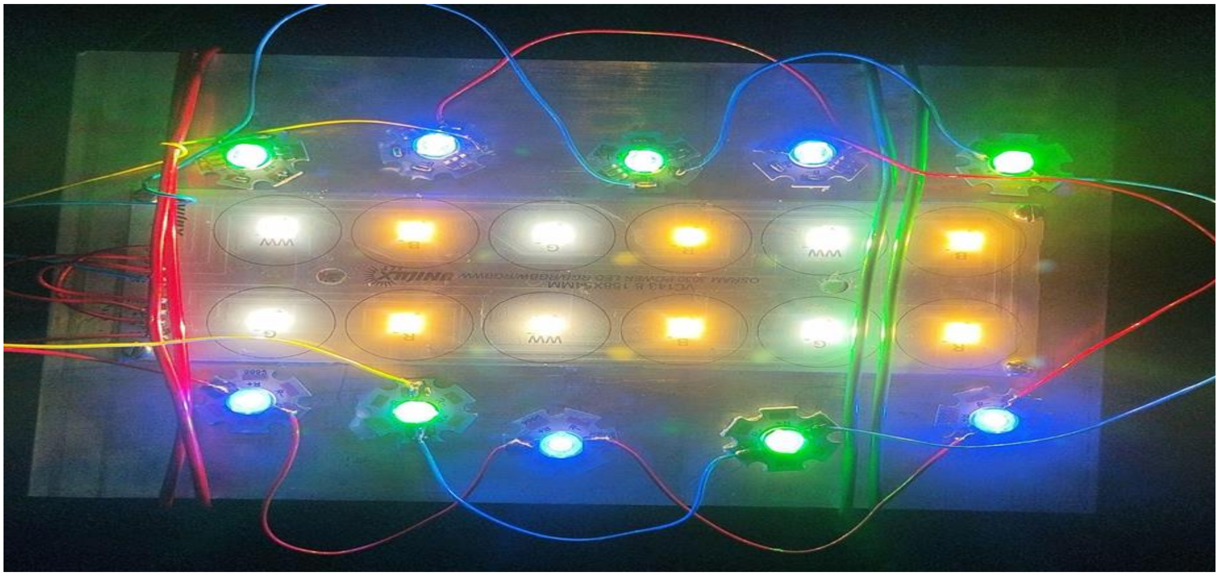
10.1.1 Sample-1: Here we have tested the LED light sources that are available in the market. We have mixed warm white and cool white LED light sources.(WW+CW).



10.1.2 Sample-2 : Here we have tested the LED light sources that are available in the market.We have mixed warm white,green and blue LED light sources.(WW+G+B)

10.1.3 Sample-3: Here we have tested the LED light sources that are available in the market. We have mixed warm white and cool white LED light sources with a halogen PAR lamp (WW+G+B+Halogen PAR Lamp) of 50W(MR-16)

10.1.4 Sample-4: Here we have tested the LED light sources that are available in the market. We have mixed warm white and cool white LED light sources with the green and blue LEDs.(WW+CW+G+B)



10.2 Results of the Laboratory Experiments:

10.2.1 Parameters of the Basic Lamps and LEDs:

(i) Halogen PAR Lamp:

Electrical Parameters: AC Supply of 50W

Photometric Parameters: **CCT=2804K** ; Duv=0.0031 E=240 Lux

Ra=94.2 R9=73.5

Chromaticity Coordinate x=0.4567 y=0.4182

(ii) Warm white LED:

Electrical Parameters: DC Supply of 17.3V, 530mA

Photometric Parameters: **CCT=2730K** ; Duv=0.0006 E=257 Lux

Ra=84 R9=11.7

Chromaticity Coordinate x=0.4583 y=0.4118

(iii) Cool white LED:

Electrical Parameters: DC Supply of 17.3V, 530mA

Photometric Parameters: **CCT=5629K** ; Duv=0.0018 E=257 Lux

Ra=88 R9=73.7

Chromaticity Coordinate x=0.3295 y=0.3421

(iv) Green LED:

Electrical Parameters: DC Supply of 14.5V, 320mA

Photometric Parameters: E=74.1 Lux, Peak Wavelength= 527 nm

Chromaticity Coordinate x=0.1666 y=0.7353

(v) Blue LED:

Electrical Parameters: DC Supply of 15.5V, 350mA

Photometric Parameters: E=18.5 Lux ,Peak Wavelength= 463 nm

Chromaticity Coordinate x=0.1442 y=0.0455

10.2.2 Photometric and Electrical Parameters of the light source samples using above light source

Sample-1:

Electrical Parameters:

Warm White LED Input= 45V, 700mA Cool White LED Input= 45V,700mA

Photometric Parameters of Sample-1:

CCT=3750K E=707 LUX Duv=-0.0040

Ra=91.9 **R9=49**

Chromaticity Coordinate : x=0.3887, y=0.3731

Sample-2:

Electrical Parameters:

Warm White LED Input= 30V, 460mA, R=2.2 ohm/10W

Green LED Input= 20V, 320mA, R=19.5 ohm/4W

Blue LED Input= 20V, 350mA, R=5E/4W

Photometric Parameters of Sample-2:

CCT= 2567 K E= 81.8 LUX Duv = 0.0072

Ra= 83.9 **R9= 13.2**

Chromaticity Coordinate : x=0.4848, y=0.4360

Sample-3:

Electrical Parameters :

Warm White LED Input= 30V, 460mA, R=2.2 ohm/10W

Green LED Input= 20V, 320mA, R=19.5 ohm/4W

Blue LED Input= 20V, 350mA, R=5E/4W

Halogen PAR Lamp(MR-16) =50W

Photometric Parameters of Sample-3 :

CCT= 3785K E=149 LUX Duv= -0.0039

Ra=90.6 **R9=94.1**

Chromaticity Coordinate: x=0.3872, y=0.3726

Sample-4:

Electrical Parameters:

Warm White LED Input= 17.6V, 600mA

Cool White LED Input= 17.6V, 600mA,

Green LED Input= 14.6V, 350mA,

Blue LED Input= 15.3V, 350mA,

Photometric Parameters of Sample-4 :

CCT= 6278K E=584 LUX Duv= -0.0045

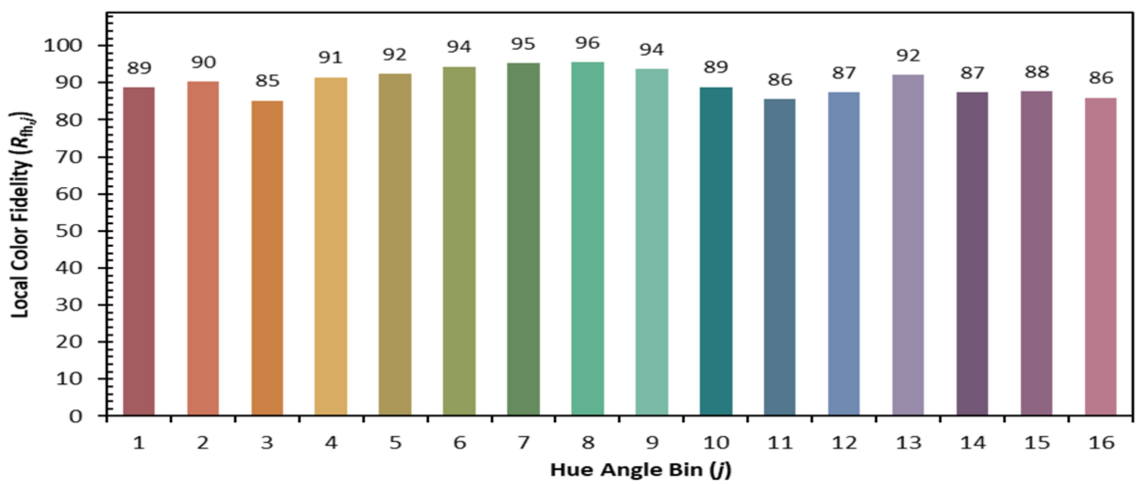
Ra=95.9 **R9=95**

Chromaticity Coordinate: x=0.3219, y=0.3259

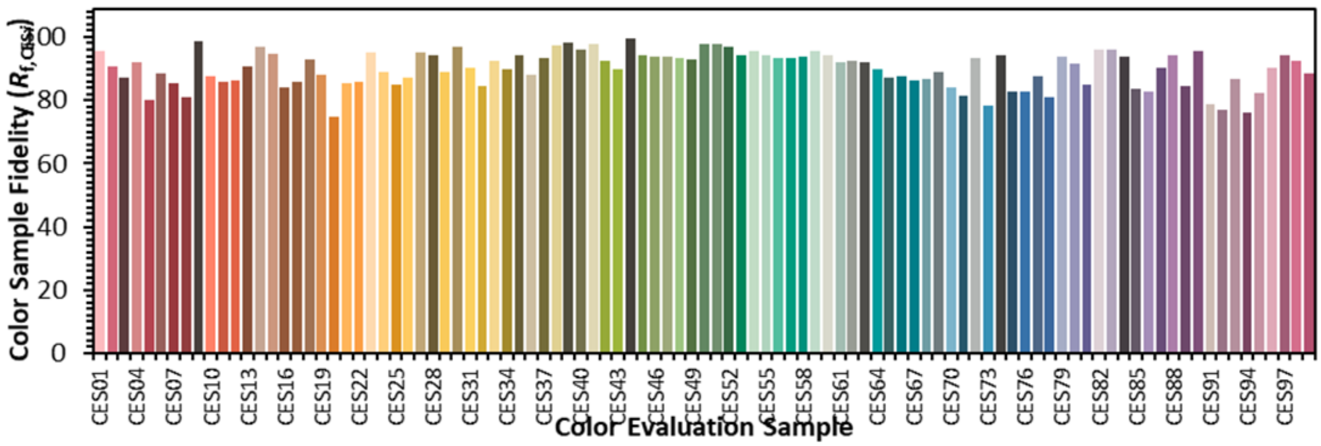
10.3 IES R_f and R_g :

(i) R_f and R_g :

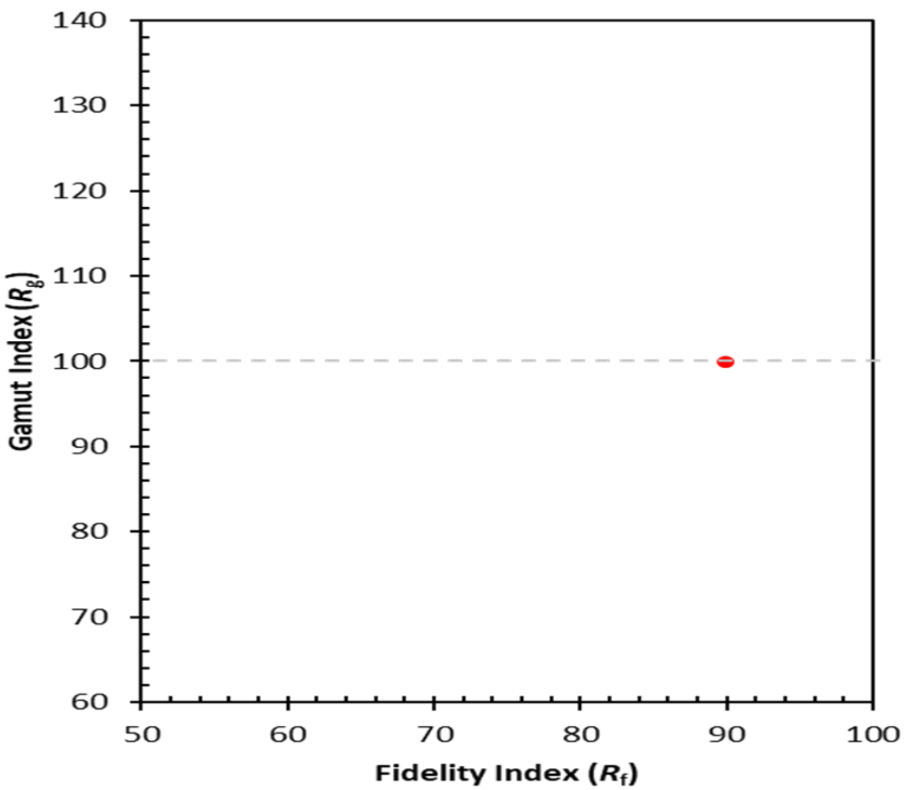
We have already discussed the Rf and Rg in previous chapters (Color quality Scale).The R_f and R_g form a complementary two measures system,which can be plotted to visually illustrate the trade off between fidelity and saturation.



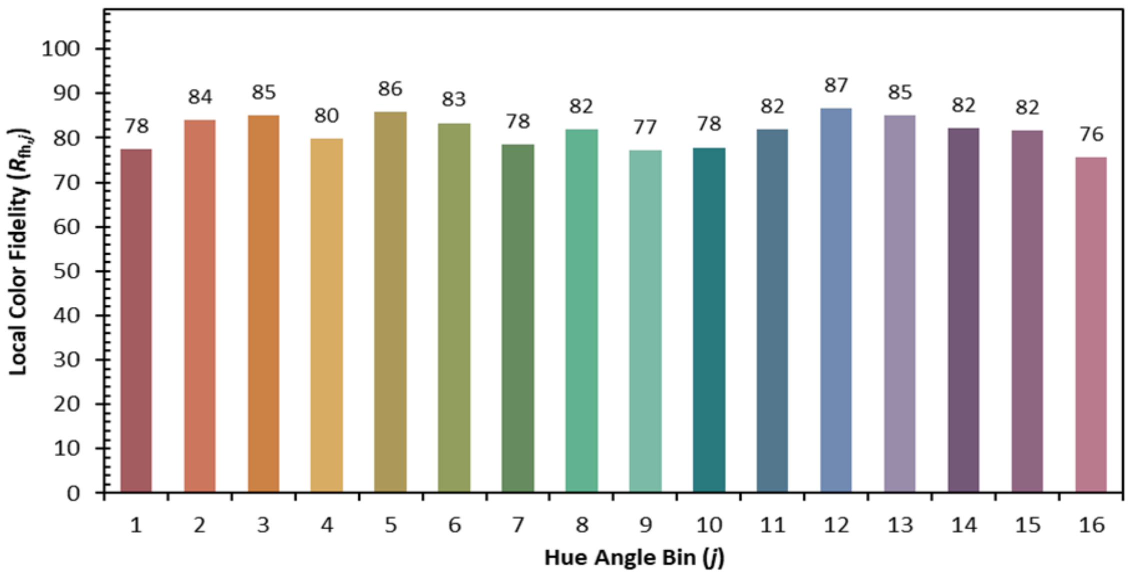
Local Color Fidelity of Sample-1



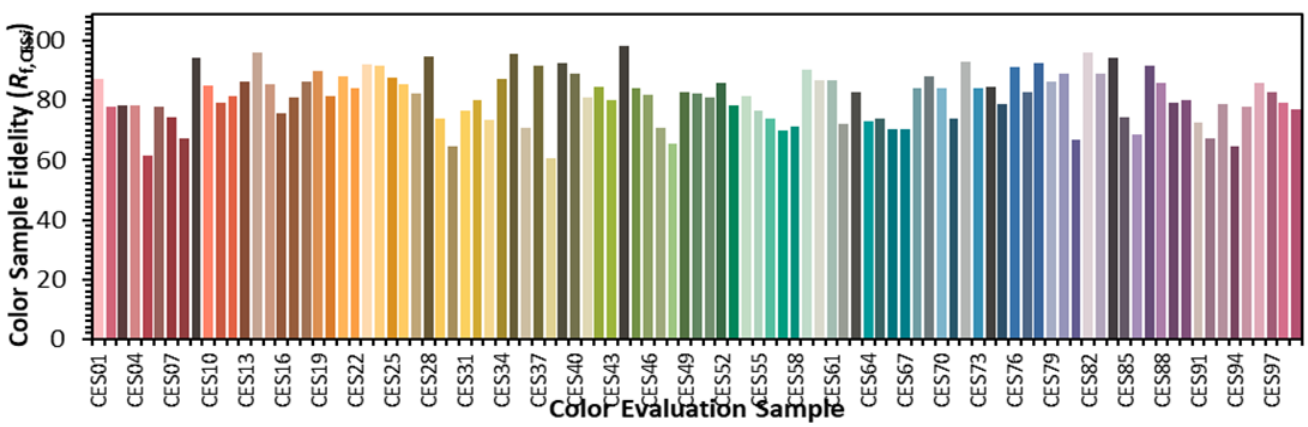
99 Color Evaluation Samples (CES) of Sample-1



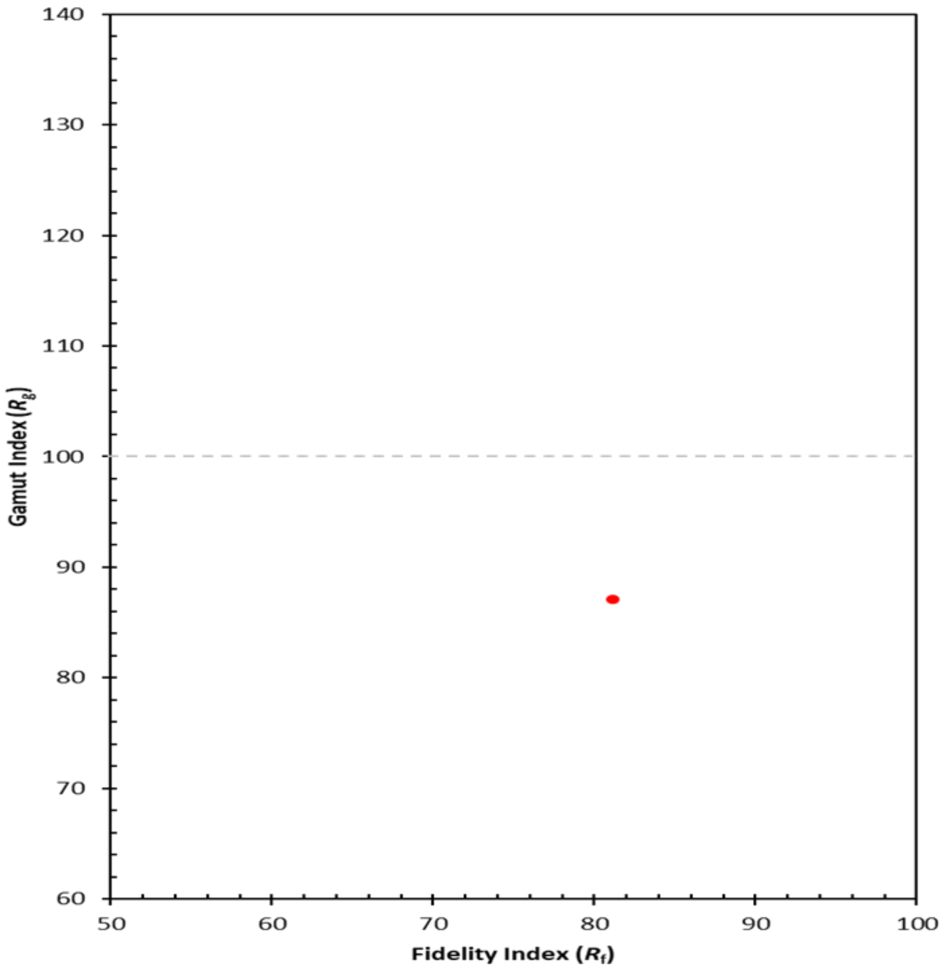
IES Rf VS Rg of Sample-1



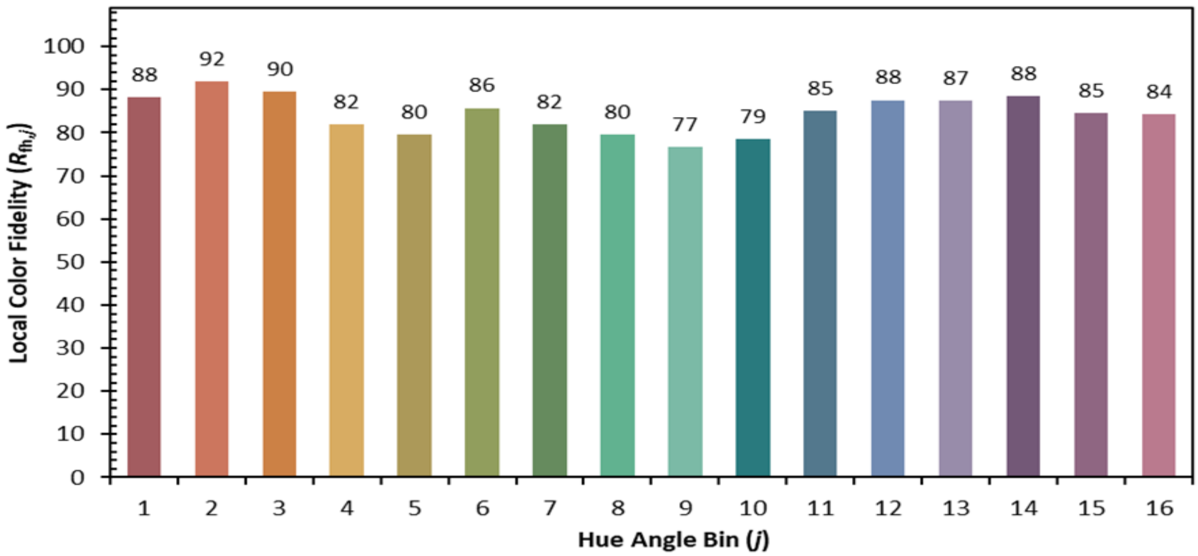
Local Color Fidelity of Sample-2



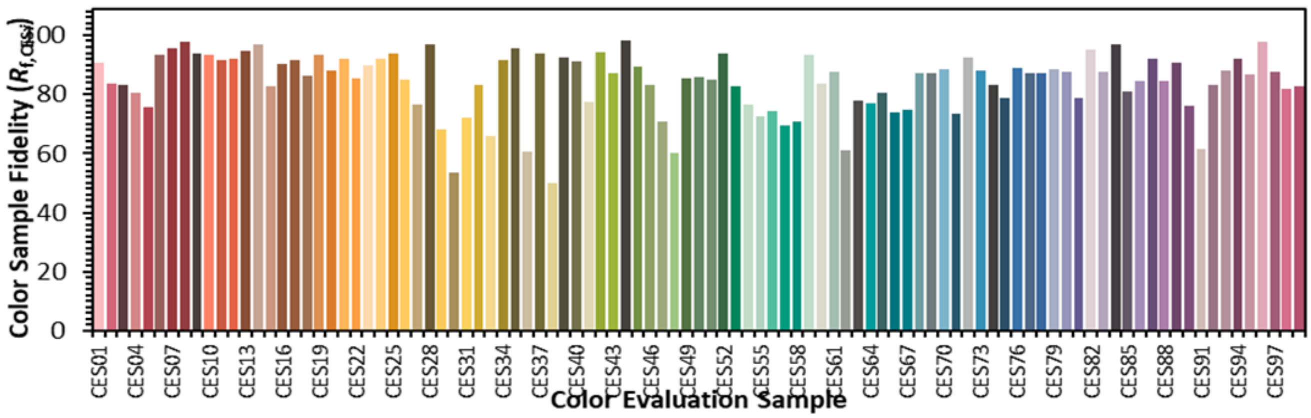
99 Color Evaluation Samples (CES) of Sample-2



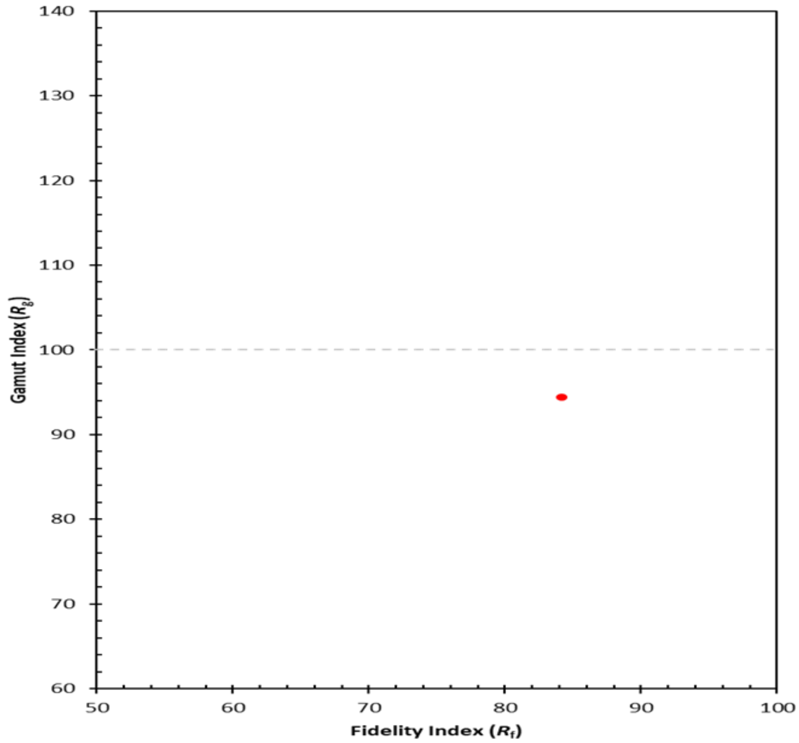
IES R_f VS R_g of Sample-2



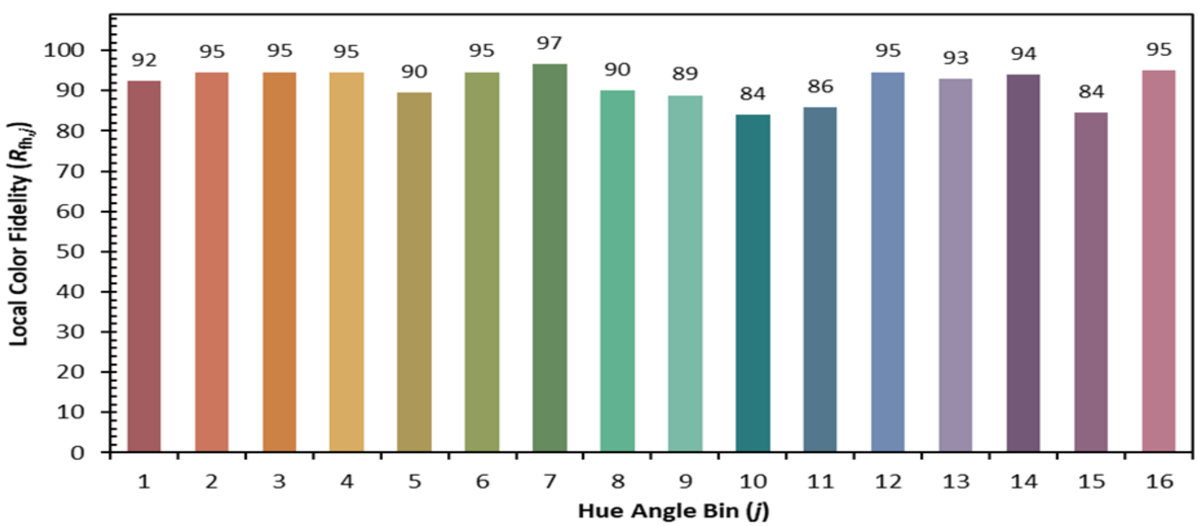
Local Color Fidelity of Sample-3



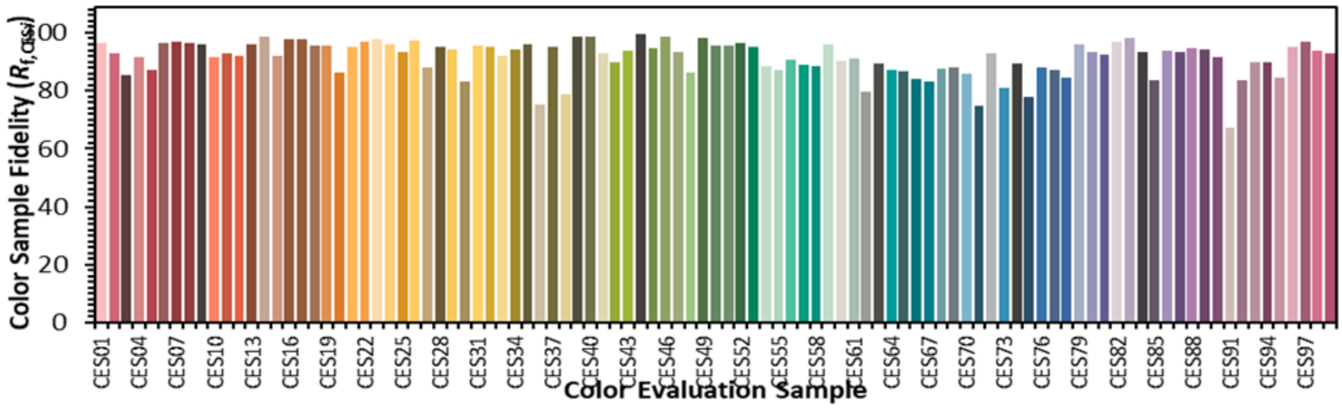
99 Color Evaluation Samples (CES) of Sample-3



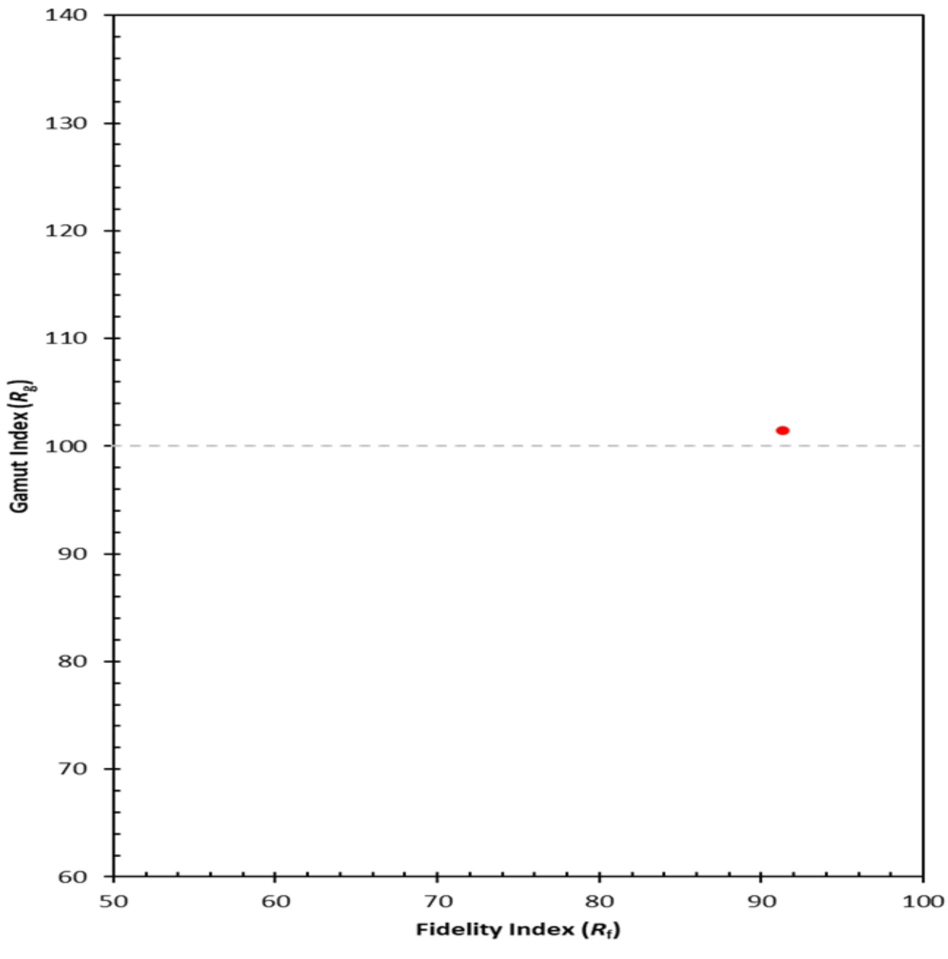
IES R_f VS Rg of Sample-3



Local Color Fidelity of Sample-4

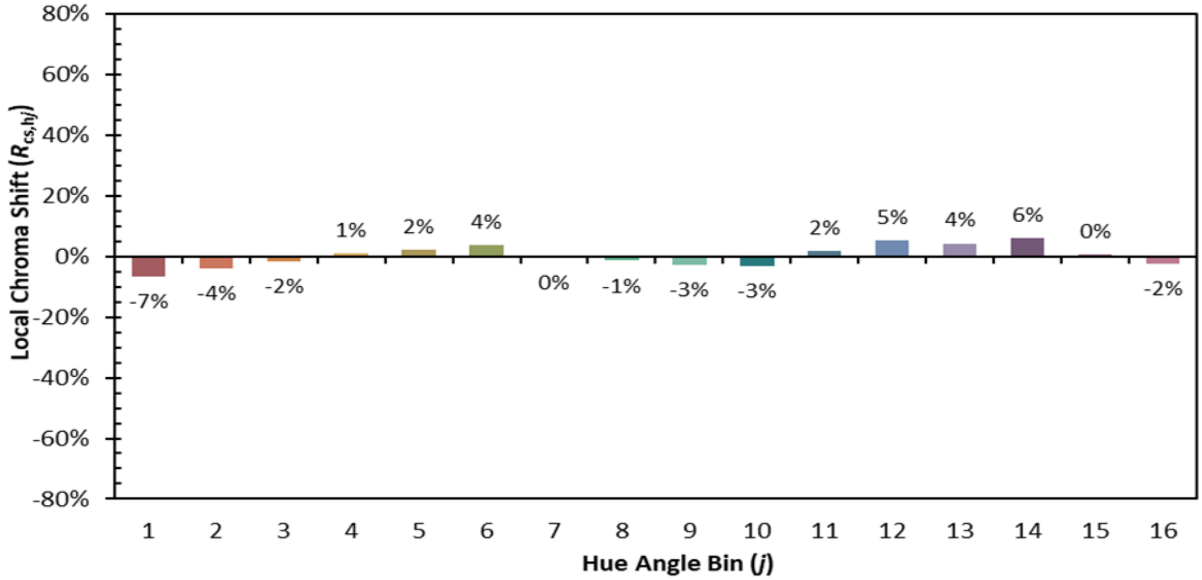


99 Color Evaluation Samples (CES) of Sample-4

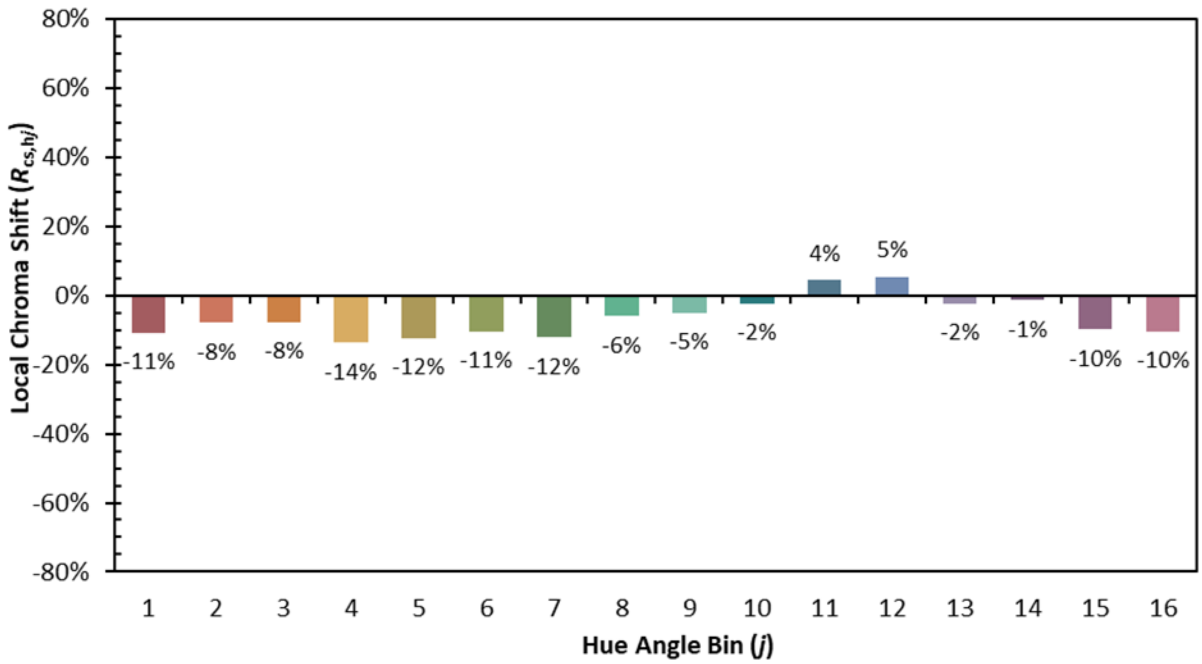


IES R_f VS R_g of Sample-4

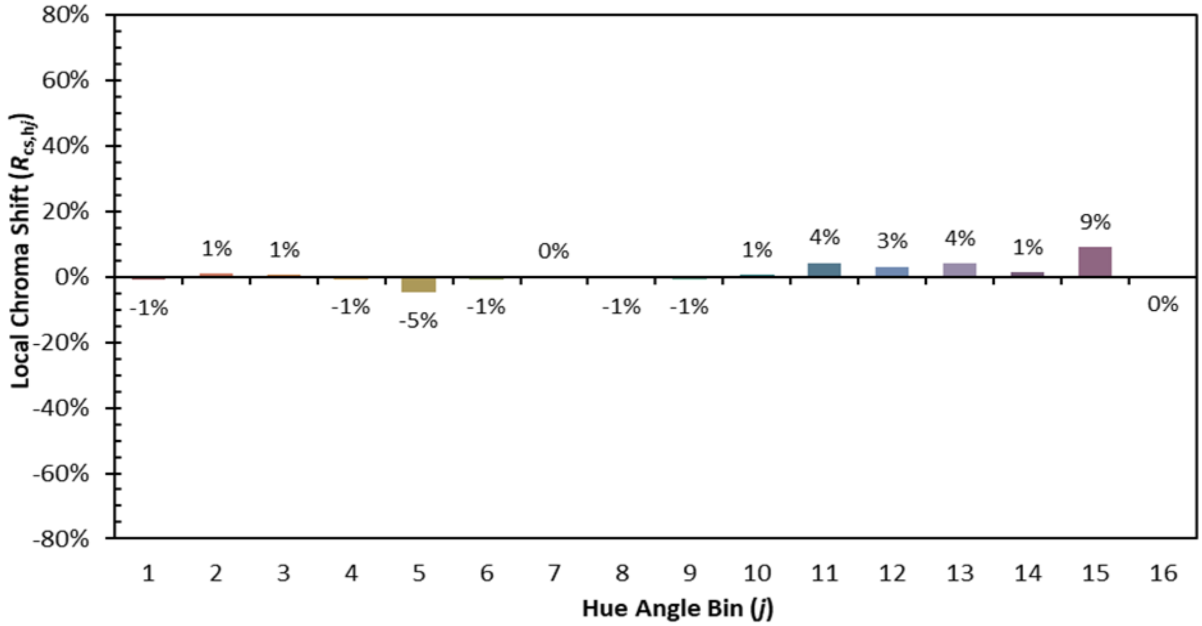
(ii) Chroma shift per hue angle bin



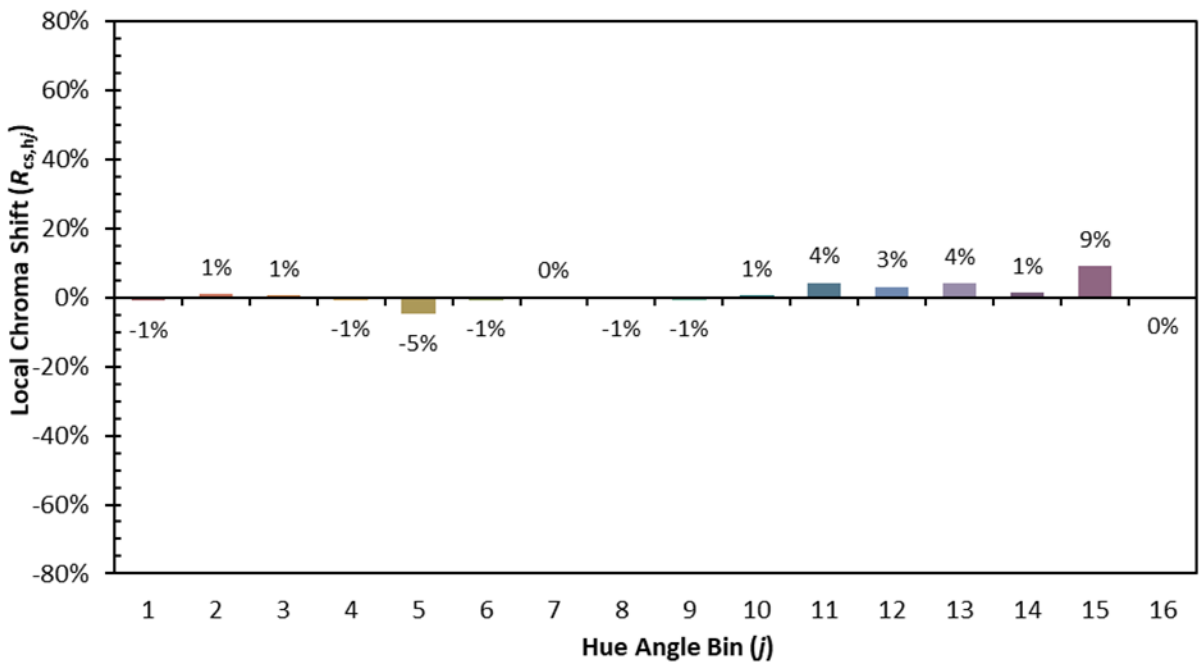
Local Chroma Shift per Hue angle Bin of Sample-1



Local Chroma Shift per Hue angle bin of Sample-2

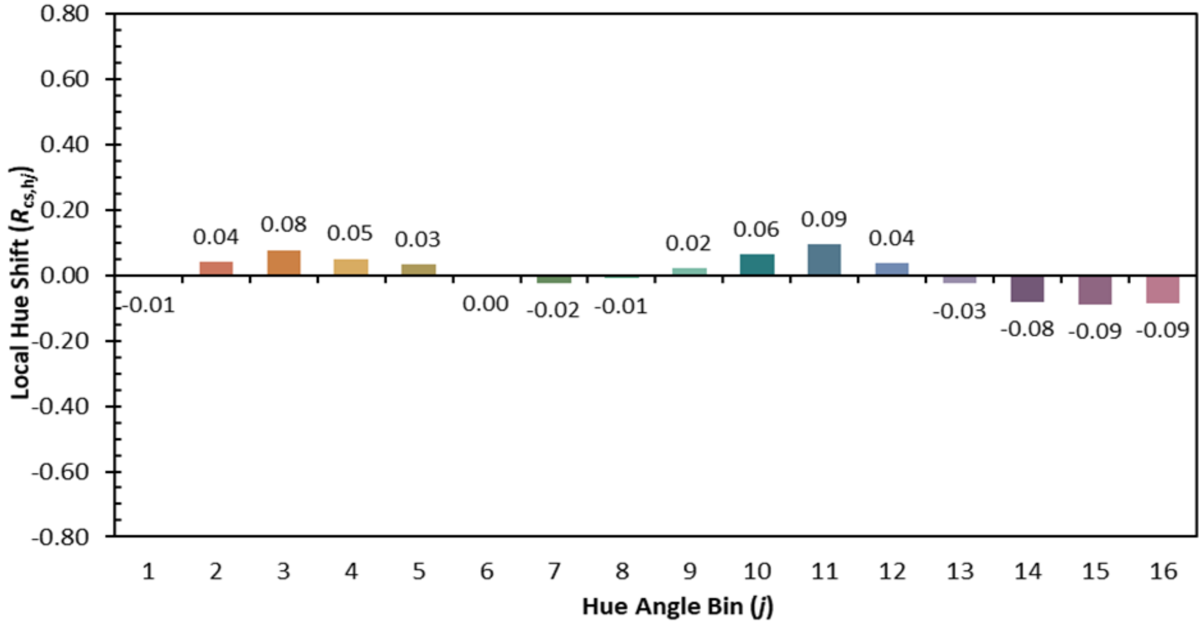


Local Chroma Shift per Hue angle bin of sample-3

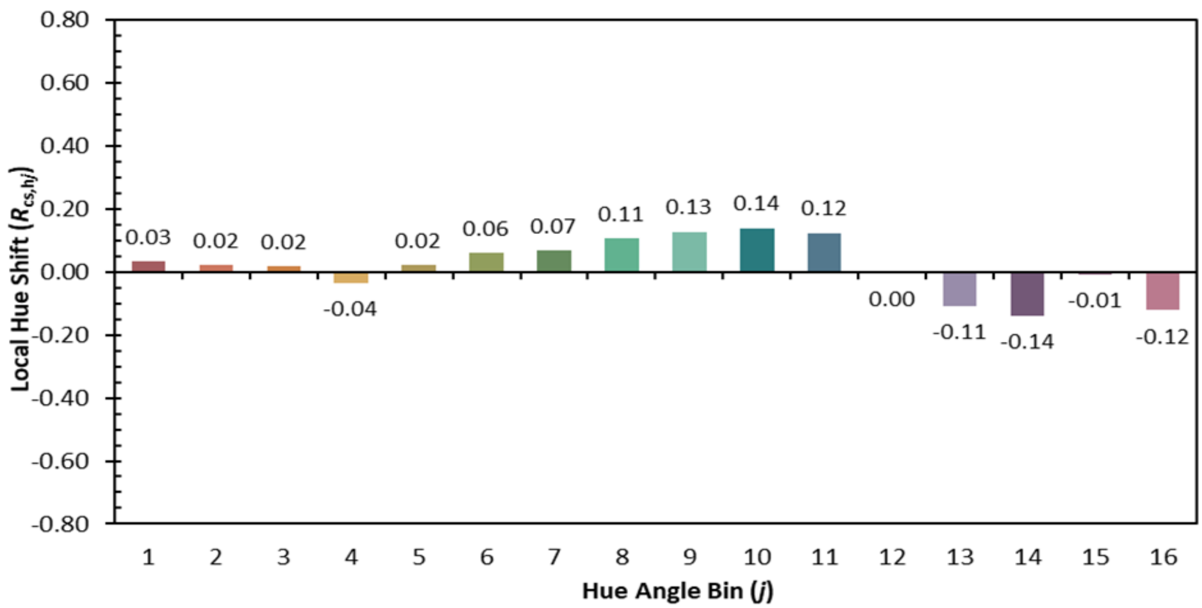


Local Chroma Shift per Hue angle bin of Sample-4

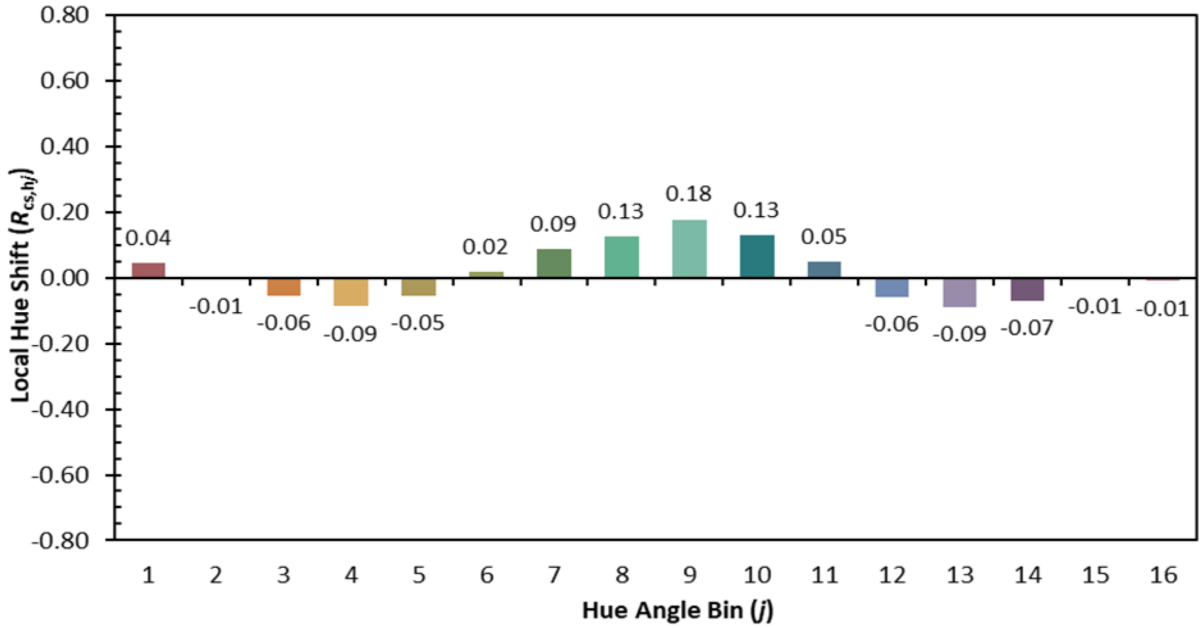
(iii) Hue shift per hue angle bin



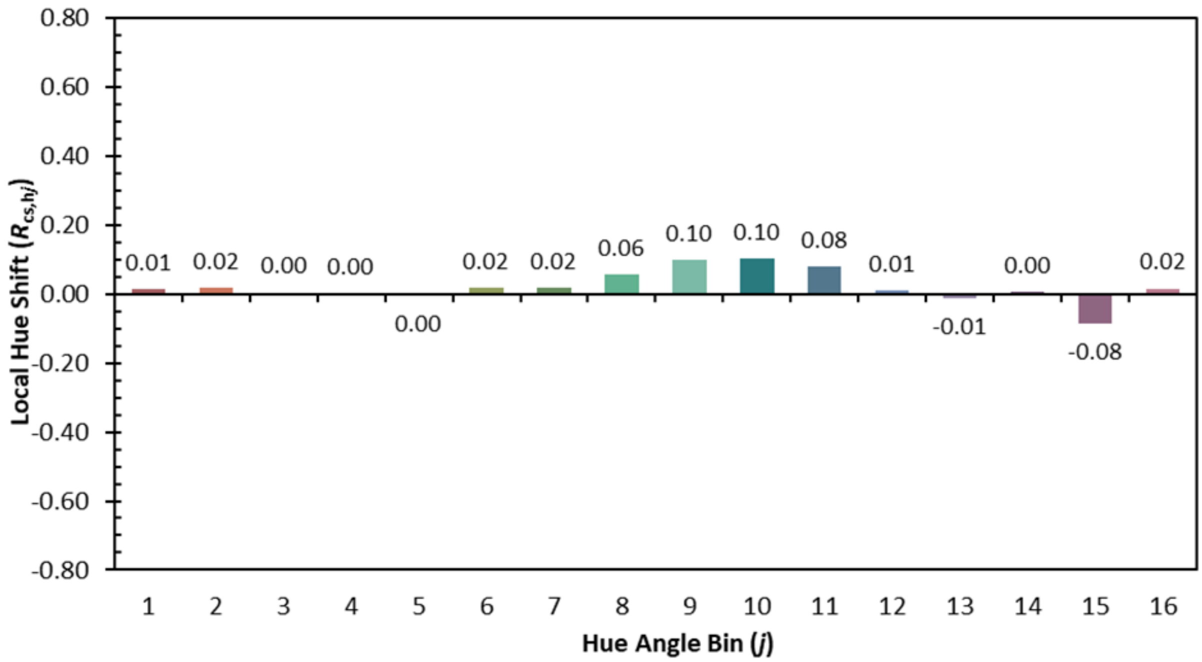
Local Hue Shift per hue angle bin of Sample-1



Local Hue Shift per hue angle bin of Sample-2

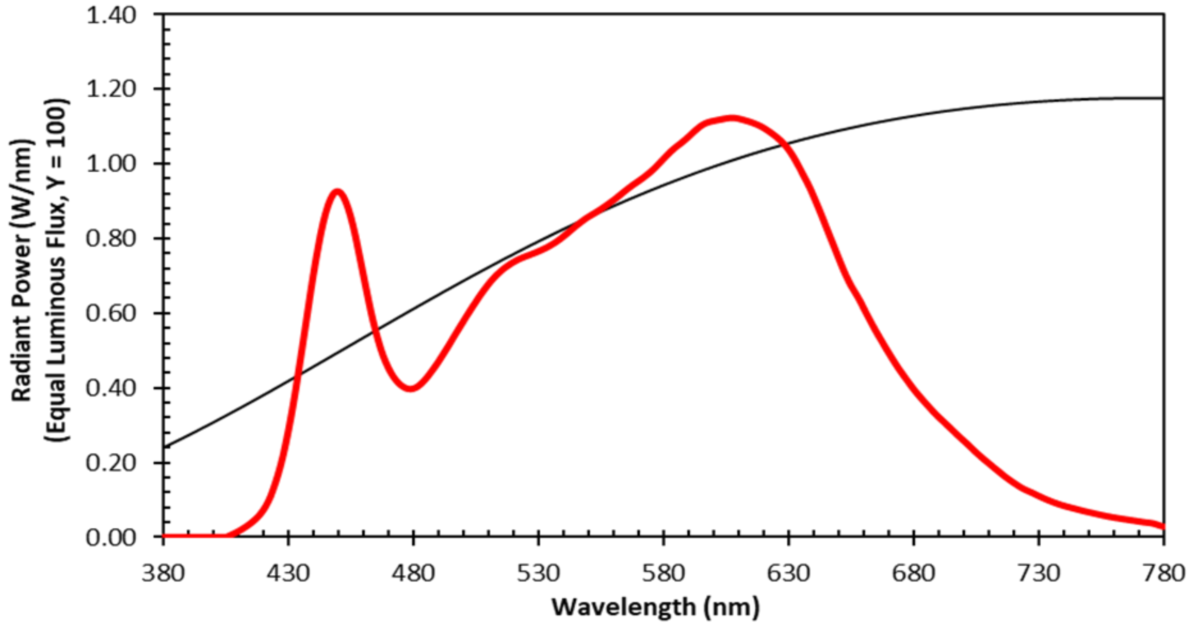


Local Hue Shift per hue angle bin of Sample-3

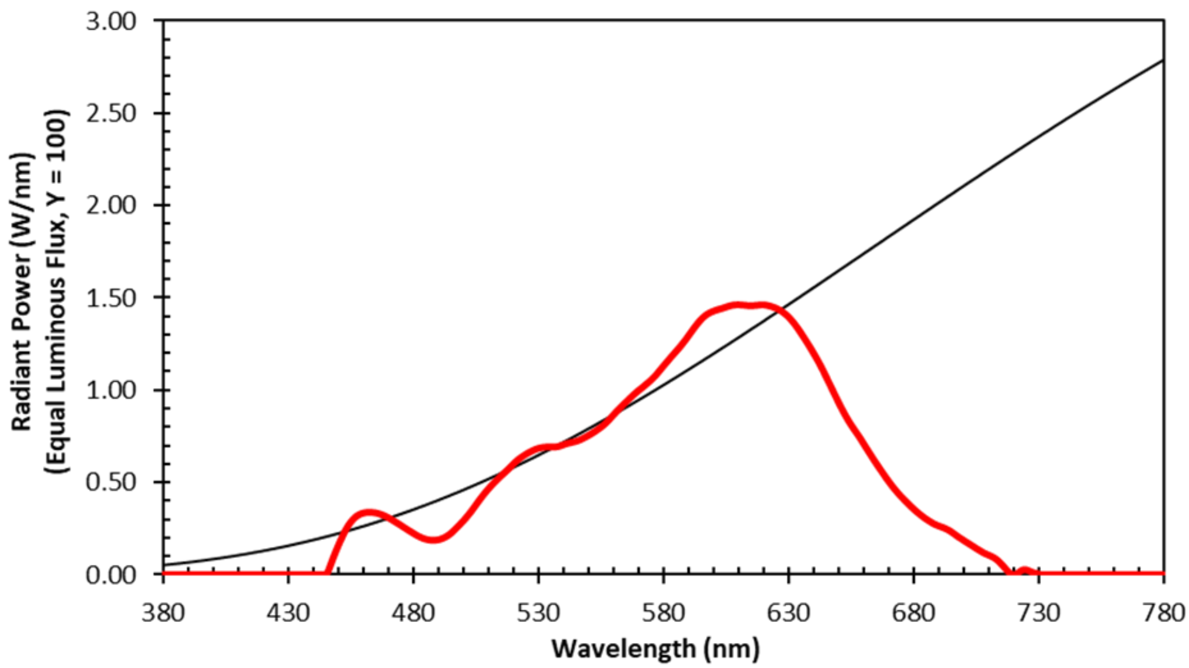


Local Hue Shift per hue angle bin of Sample-4

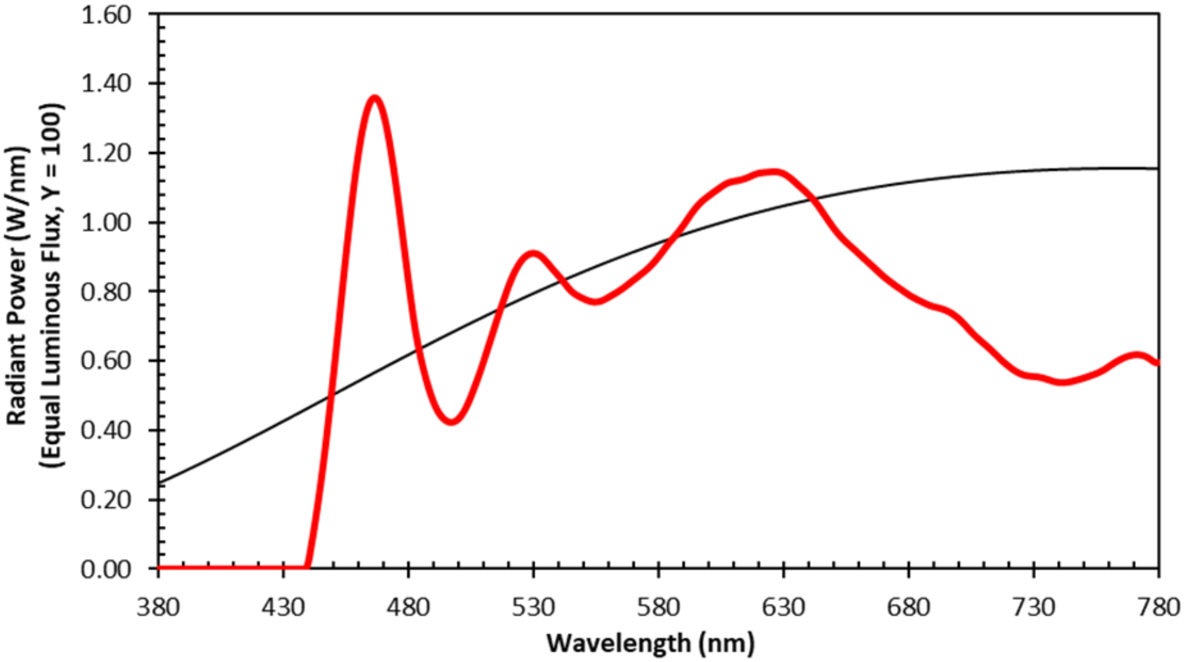
(iv) Spectral Power Distribution (SPD) of Developed Light source



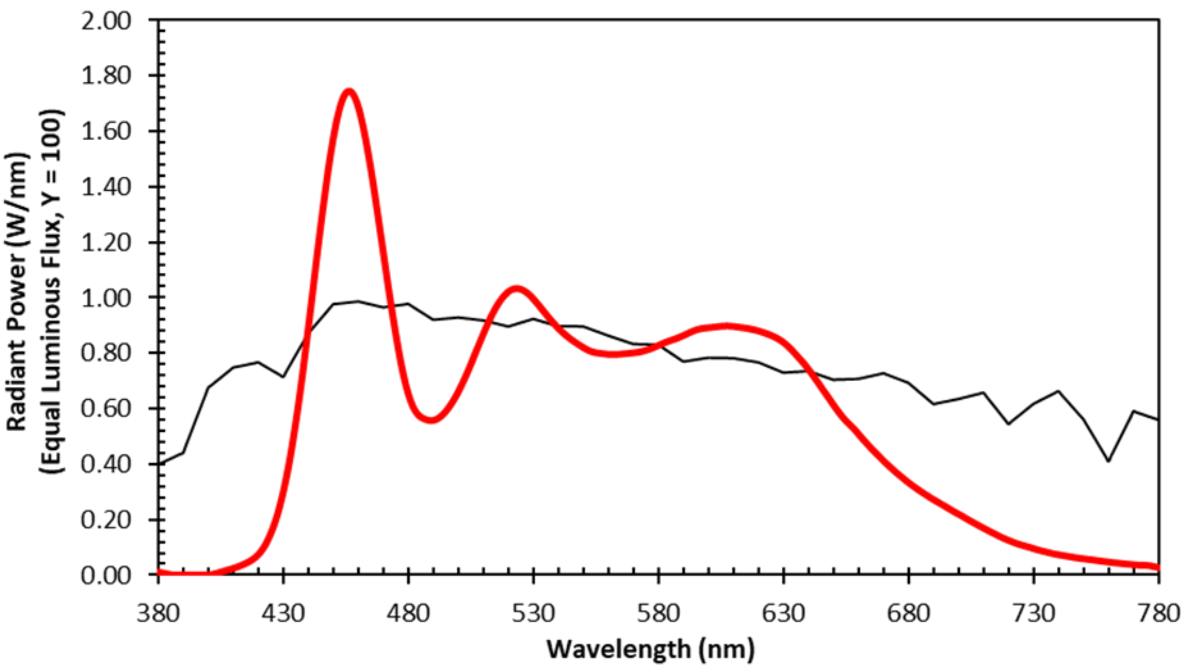
SPD of Sample-1



SPD of Sample-2



SPD of Sample-3



SPD of Sample-4

10.4 The final selected Light source Output:

10.4.1 Without the Lens

(i) Warm white+Cool white LEDs

Photometric Parameters:

CCT=3733K E=468 Lux Duv=-0.0046

Ra=91.2 **R9=49.4**

Chromaticity Coordinate : x=0.3260 y=0.3245

(ii) Warm white+Cool white+Green+Blue LEDs:

Photometric Parameters:

CCT=6033K E=584 Lux Duv=-0.0030

Ra=95.9 **R9=95**

Chromaticity Coordinate x=0.3219 y=0.3259

(iii) Green LEDs : E=152 Lux

(iv) Blue LEDs : E=88.5 Lux

Ratio of Illuminance : White(WW+CW) : G : B = 468 : 152 : 88.5

10.4.2 With the Lens

(i) Warm white+Cool white LEDs:

Photometric Parameters :

CCT=3733K E=2160 Lux Duv=-0.0046

Ra=91.2 **R9=49.4**

Chromaticity Coordinate : x=0.3260 y=0.3245

(ii) Warm white+Cool white+Green+Blue LEDs:

Photometric Parameters:

CCT=3733K E=584 Lux Duv= -0.0017

Ra=90.6 **R9=45.1**

Chromaticity Coordinate x=0.3965 y=0.3823

(iii) Green LEDs : E=152 Lux

(iv) Blue LEDs : E=88.5 Lux

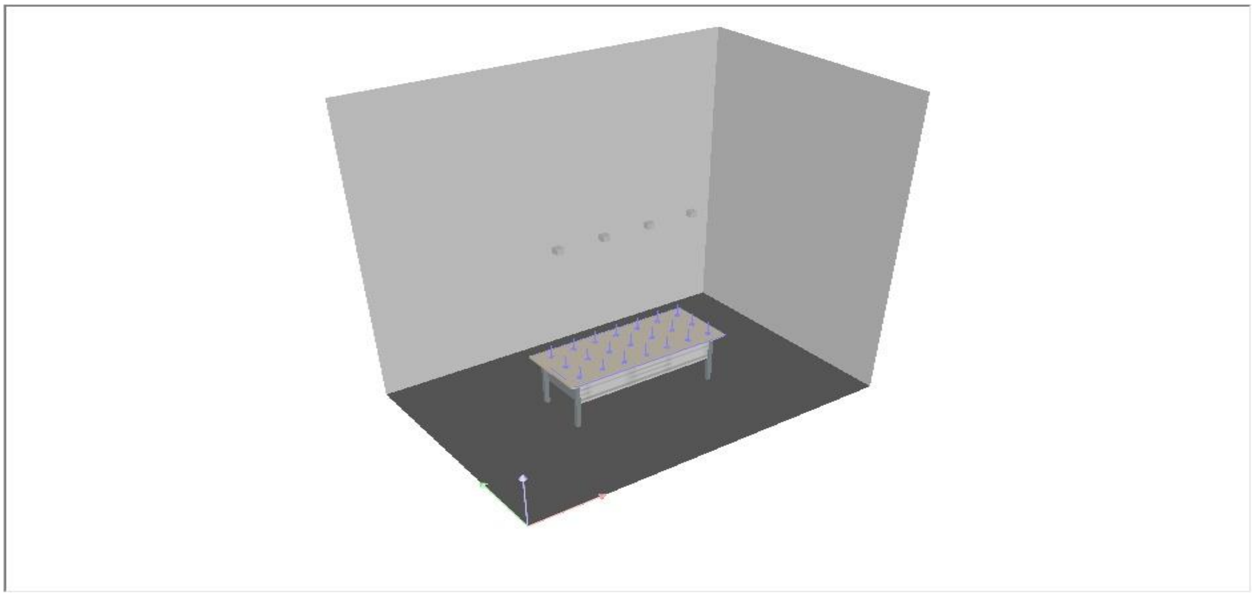
Ratio of Illuminance : White(WW+CW) : G : B = 2160 : 152 : 88.5

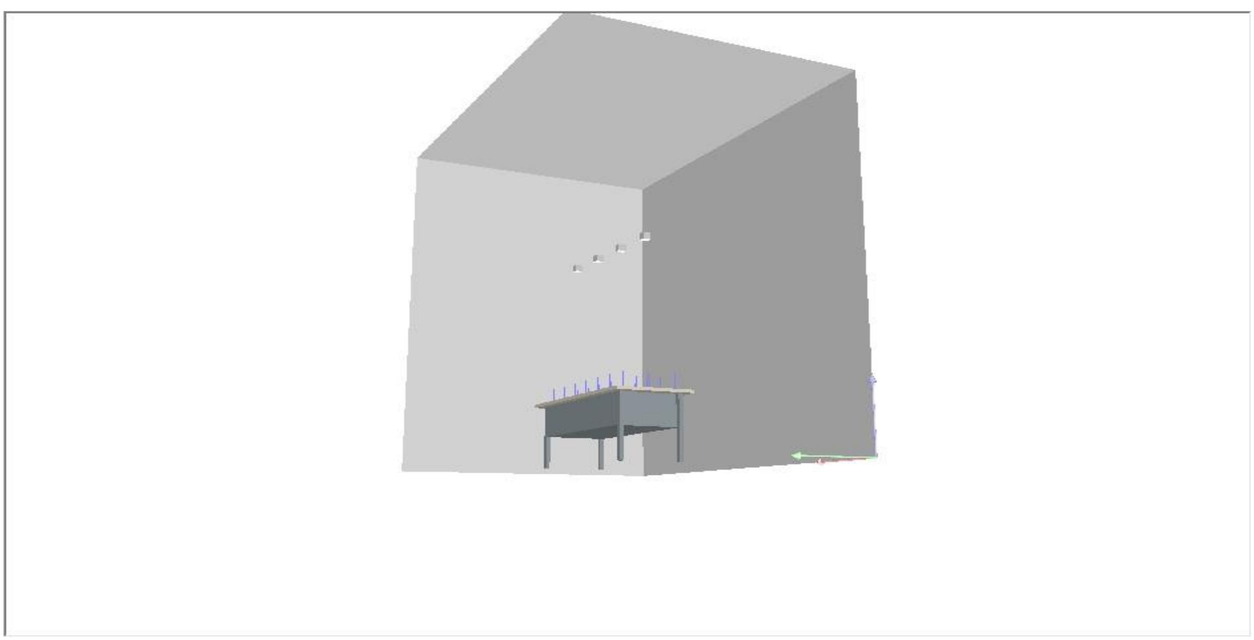
Analysis of the Results : The requirement for the critical tasks performance is the proper daylight that is proper CCT and highest possible CRI value.From the above results it is clearly seen that the sample-3 and sample 4 meets the criteria but sample 3 has some problems.The Halogen PAR Lamp emits heat and it is not compatible in fittings with the LEDs.So considering all the criteria we the sample 4 has the highest value of CRI Ra and R9 and and also daylight like CCT.So we have chosen the sample-4 as the base unit light and made multiple lights for the system to be developed for the critical tasks to be performed.The parameters especially the electrical parameters have been tested multiple times and taken the photometric measurements so that we can design the LED driver properly.All these tests were performed in the dark room where stray light can not enter.After selecting the best light source from the above samples have gone for the case study of the light source in the practical field where the critical tasks are being performed and where the color parameters play a vital role.So, we have chosen the Morgue of NRS Medical College and hospital(NRS).

CHAPTER-11 A CASE STUDY OF PERFORMANCE ASSESSMENT COLOR QUALITY USING DEVELOPED LIGHT SOURCE:

11.1Dialux Implementation of the Case Study:

11.1.1 Dialux Design





11.1.2 Dialux Output:

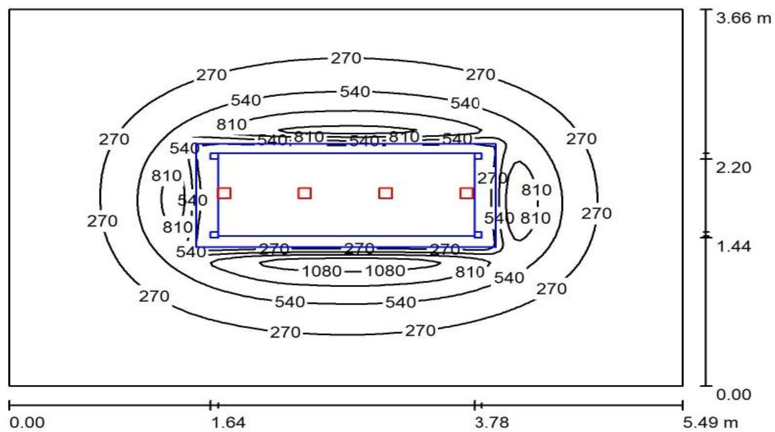
Project 1

DIALux

10.09.2023

Operator
Telephone
Fax
e-Mail

Room 1 / Single Sheet Output



Height of Room: 5.486 m, Mounting Height: 3.290 m, Light loss factor: 0.80 Values in Lux, Scale 1:47

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	283	13	1342	0.047
Floor	20	232	16	993	0.068
Ceiling	30	45	35	57	0.764
Walls (4)	30	58	20	172	/

Workplane:
Height: 0.760 m
Grid: 128 x 128 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.197, Ceiling / Working Plane: 0.160.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	Indoor light LED indoor Light (1.000)	3483	3485	67.0
			Total: 13930	Total: 13939	268.0

Specific connected load: 13.36 W/m² = 4.72 W/m²/100 lx (Ground area: 20.06 m²)

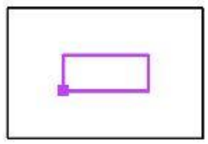
Page 1

1576	1846	2026	2010	2005	1851	1530
2182	2355	2779	2552	2736	2384	2121
1568	1916	2074	2082	2068	1916	1586

0.50 m
-0.50
-1.20
1.20 m

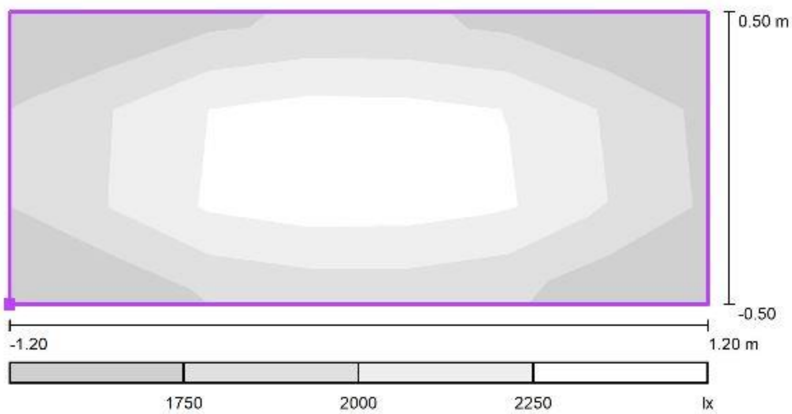
Values in Lux, Scale 1 : 18

Position of surface in room:
Marked point: (1.572 m, 1.329 m, 1.000 m)



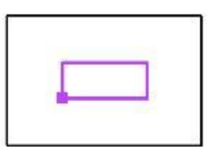
Grid: 7 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
2055	1530	2779	0.74	0.55



Scale 1 : 18

Position of surface in room:
Marked point: (1.572 m, 1.329 m, 1.000 m)



Grid: 7 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
2055	1530	2779	0.74	0.55

11.2 Practical Implementation of the Case Study:

We have selected an area of 6 ft x 6 ft as our working plane where critical tasks are to be performed. Light sources were placed at height of 7.5 ft from the working plane. Here we have used 4 LED luminaires in a plane of length of 6 ft for this working plane area.

11.2.1 Practical System set up:

First of all we arranged four luminaires in a frame of length 6 ft and mounted at a height of 8 ft. The distance between the two luminaires is near about 5 inches.

11.3 Output and Analysis of the Case Study:

The output of whatever we got in our laboratory closely matches the output of the case study in NRS Medical College and Hospital. But the Lens we have used in green and blue LEDs having narrow angle so greenish and bluish spot were coming in the working plane. We have tried to remove the spot of green and blue by using wide beam angle lens but we could not remove the spot. So we have used the frame (white color) of that green and blue lenses excluding the lens which have some reflectance and successfully got the result which closely matches the CRI Ra and R9 and other data also. So we made another Sample of light source that is Sample-5.The details of the Sample-5 is discussed below along with the practical set up and results of that case study has also been added here.

Working plane with the Lens

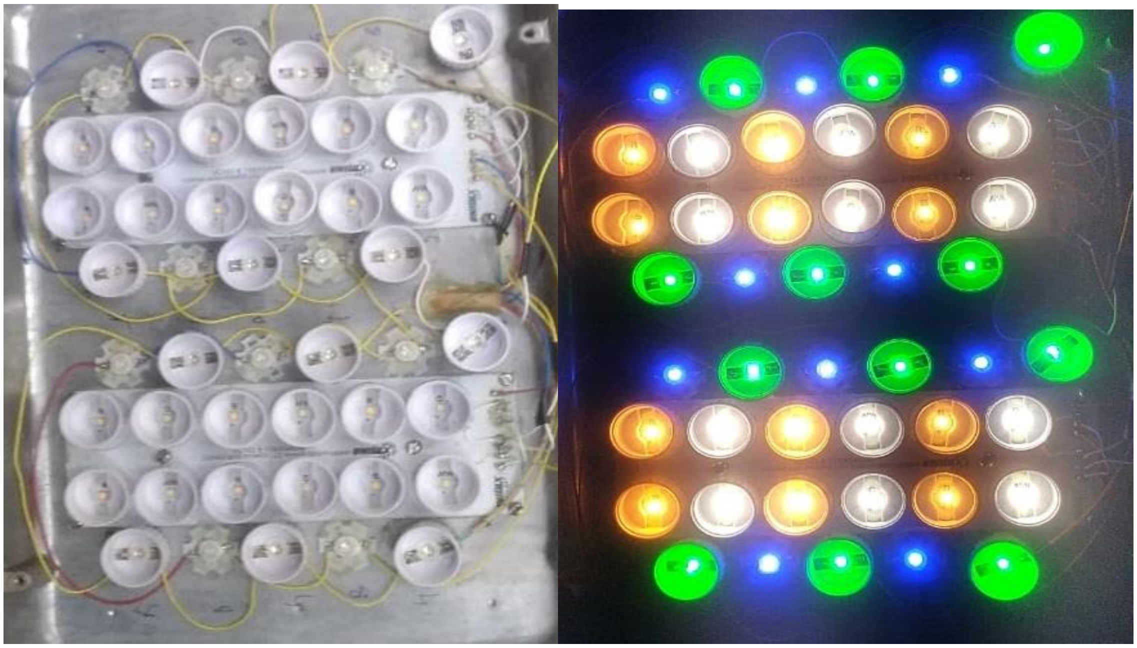
11.4 LED Light Source Sample-5 and Sample-6:

To remove the green and blue spot we have removed the narrow beam angle lens and used the wider beam angle lens. After using wider beam angle we could not be able to remove the spot. So we were compelled to remove the lens of Blue and green LEDs.

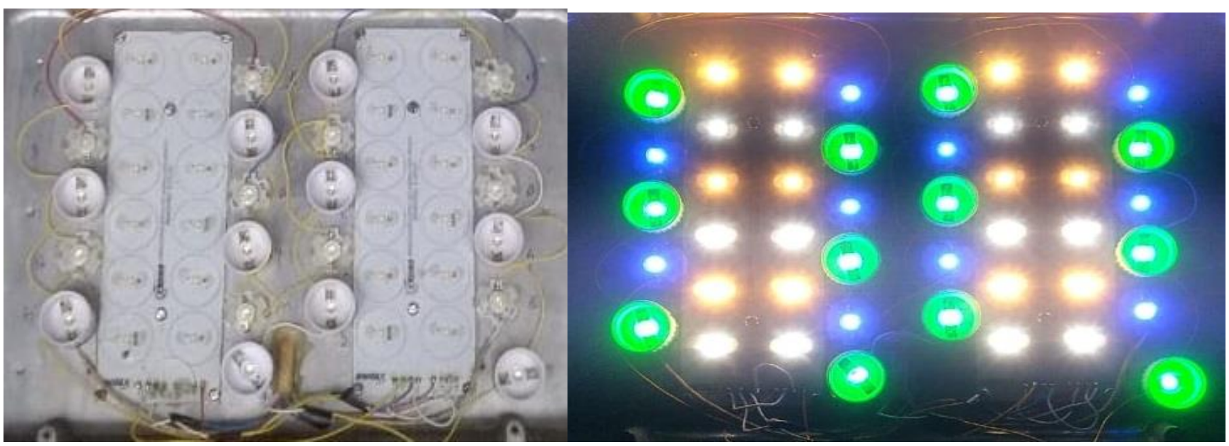
Firstly we removed all the Lenses of Blue and green LEDs and kept the Lens of Warm white and cool white LEDs and took the photometric parameters. We were able to remove the spot but it was having poor color quality that is source has low CRI and low R9.The only cause behind that is after removing the lens of blue and green color their illuminance contribution reduced and we could not maintain the ratio of illuminance of white(warm and cool),green and blue though the lux level of blue was enough.

If we want to maintain the ratio of illuminance we have to increase the contribution of green.To increase the illuminance of green either we have to increase the current or number of LEDs.We can not increase the current of green because it is at maximum level (350 mA).So we increased the number of LEDs and due to the number of LEDs are limited as the the designed source area is fixed for a light source.So to increase its contribution to maintain the illuminance level we added the white frame of the lens (not lens) on Green LEDs but we could not maintain the ratio.

So finally we have removed the Lens of White LEDs lens(warm and cool both) keeping the white frame of the lens on green LEDs and giving the better color quality that is high CRI and R9 and proper CCT that closely matches the Daylight.



Light Source Sample-5



Light Source Sample-6

Electrical Parameters of Sample-5:

DC Supply : Warm White: 24-40V, 700mA Cool white: 24-40V, 600mA

Green: 24-40V, 350mA Blue : 24-40V, 350mA

Photometric Parameters of Sample-5:

CCT= 6115K E= 1730 Lux Duv=-0.0042

Ra= 94.8 **R9=93.7**

Electrical Parameters of Sample-6:

DC Supply : Warm White: 24-40V, 700mA Cool white: 24-40V, 600mA

Green: 24-40V, 350mA Blue : 24-40V, 350mA

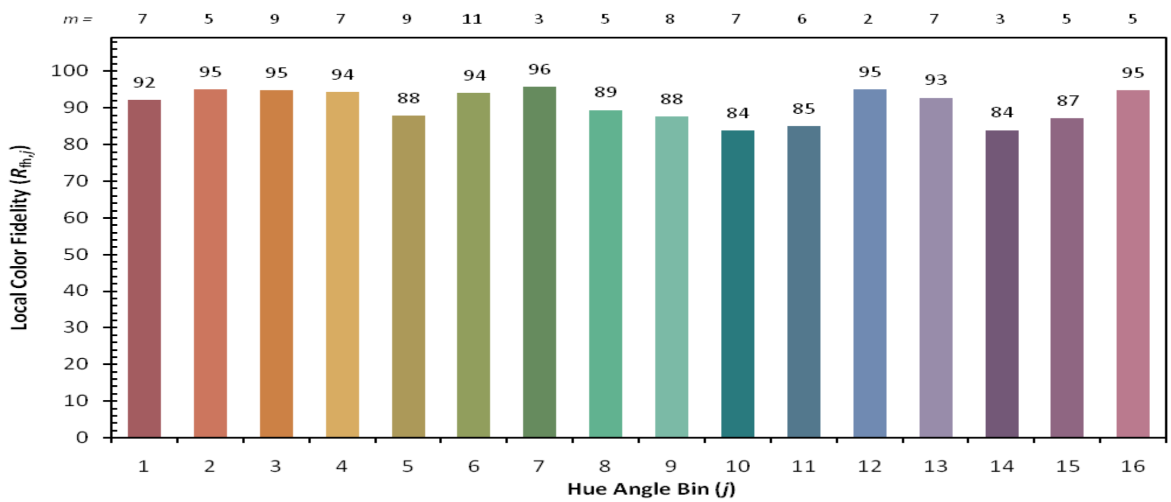
Photometric Parameters of Sample-6:

CCT=6822K E= 1490 Lux Duv= -0.0022

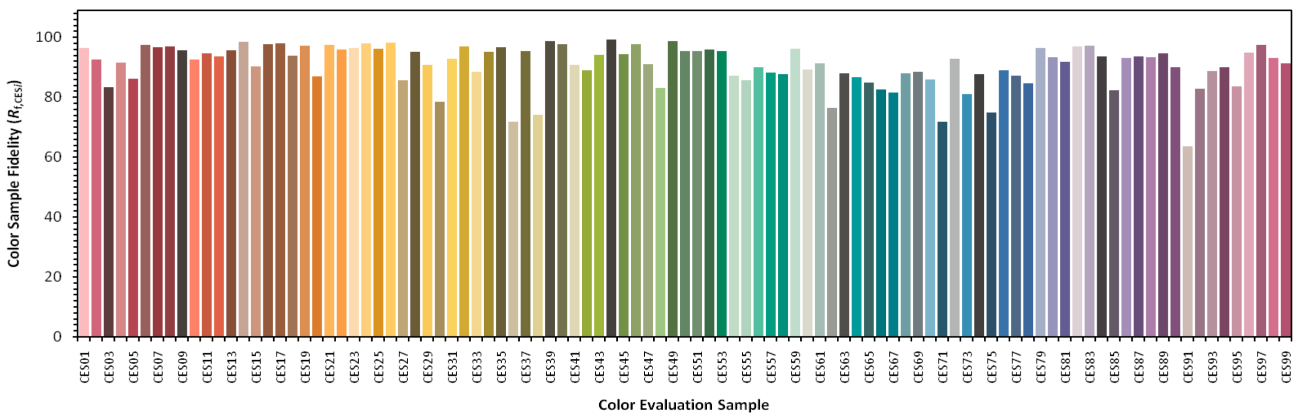
Ra= 95.2 **R9= 94.6**

11.5 IES R_f and R_g Data :

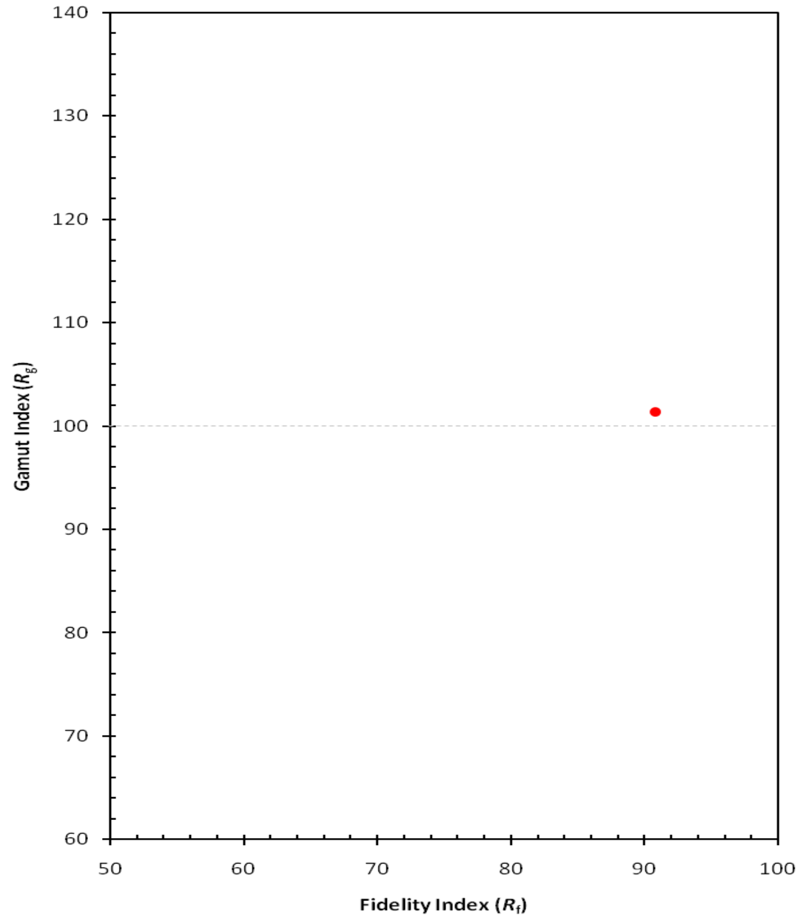
(i) R_f and R_g :



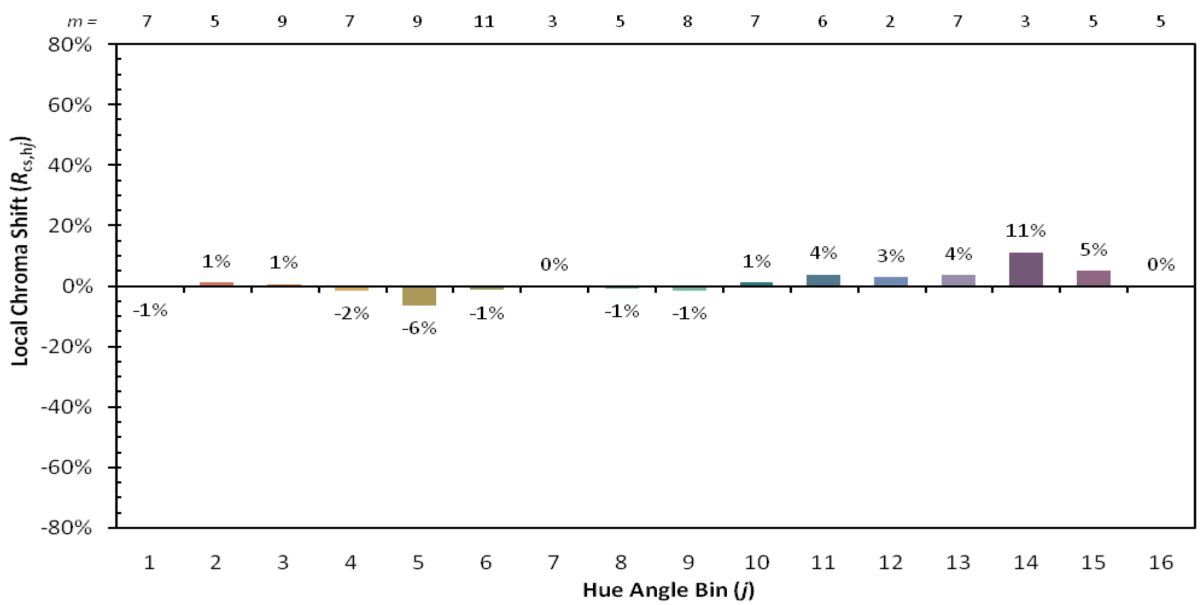
Local color fidelity of sample-5



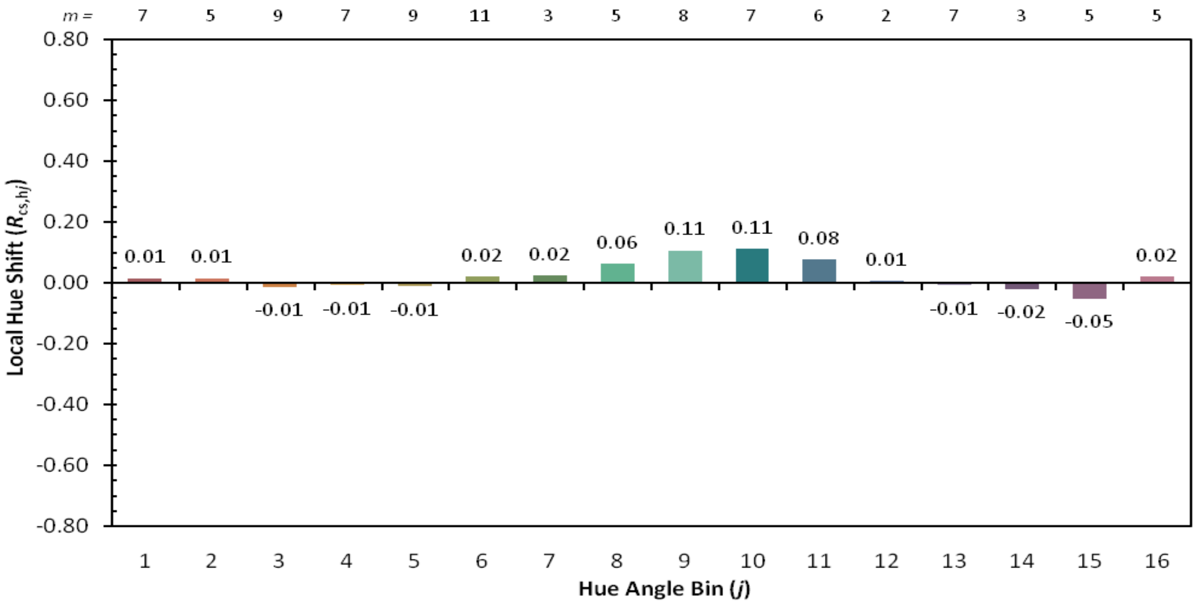
99 color Evaluation Samples(CES) of sample-5



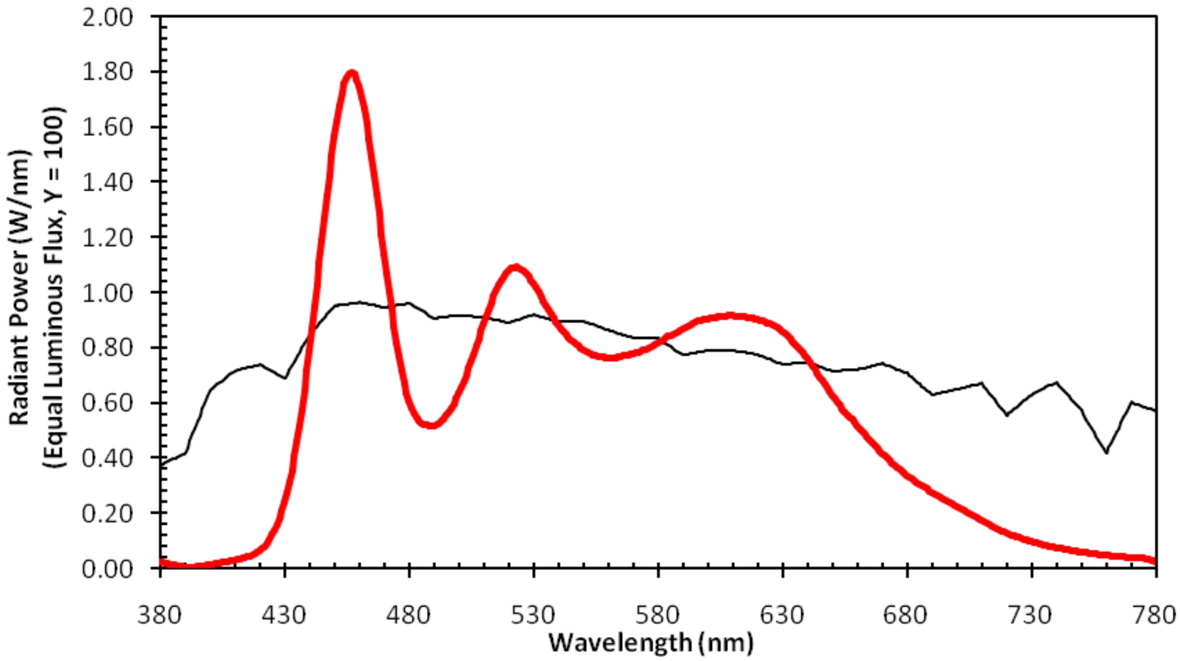
IES R_f VS R_g Sample-5



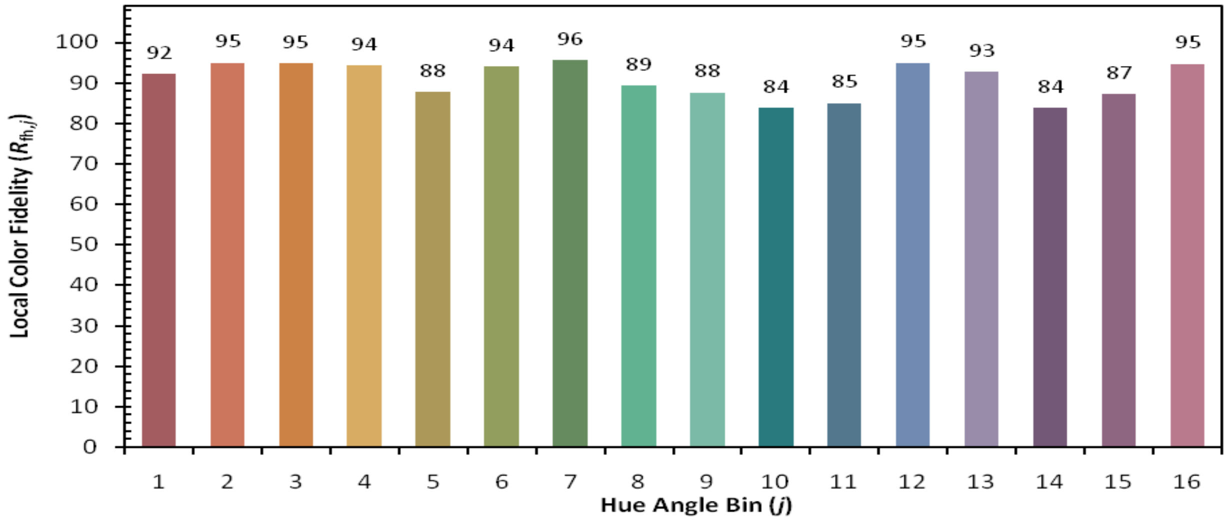
Local chroma shift of sample-5



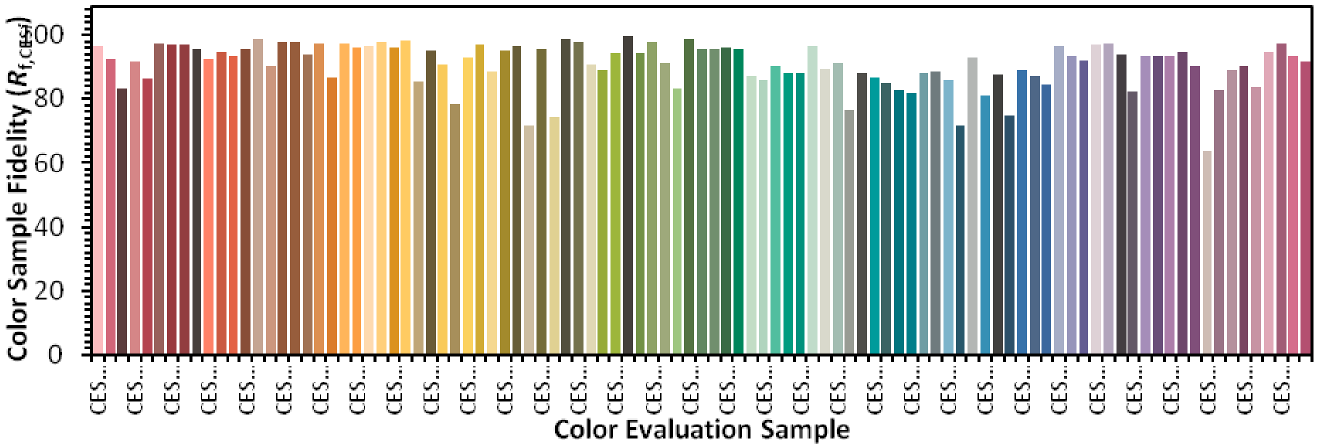
Local chroma shift of sample-5



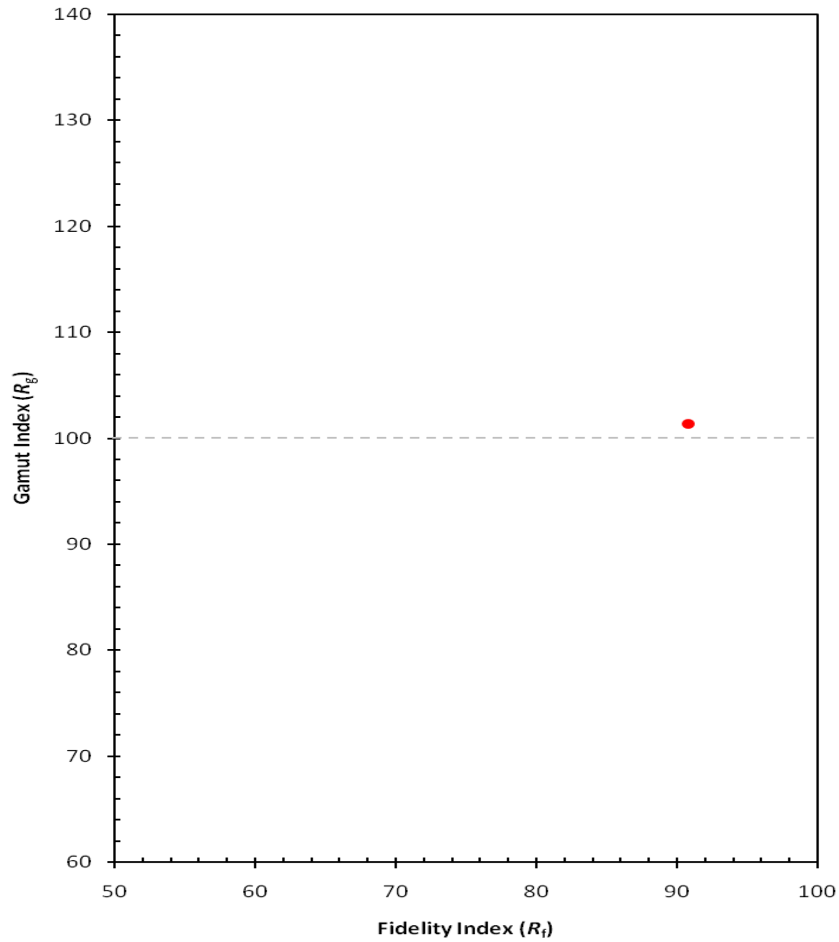
SPD of Sample-5



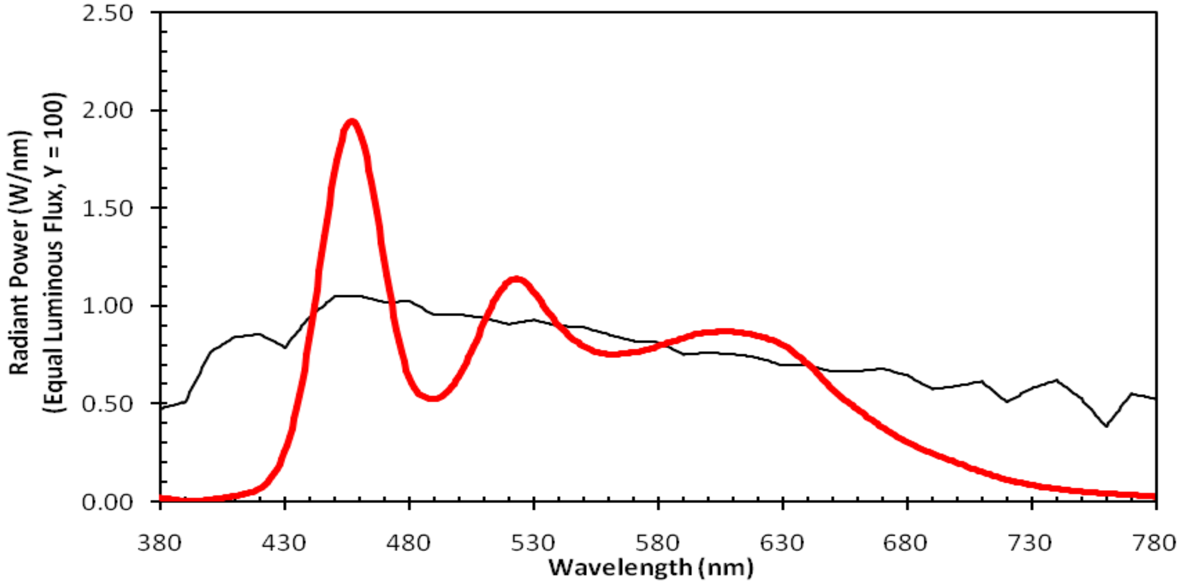
Local Color fidelity of Sample-6



99 Color Evaluation Samples (CES) of Sample-6

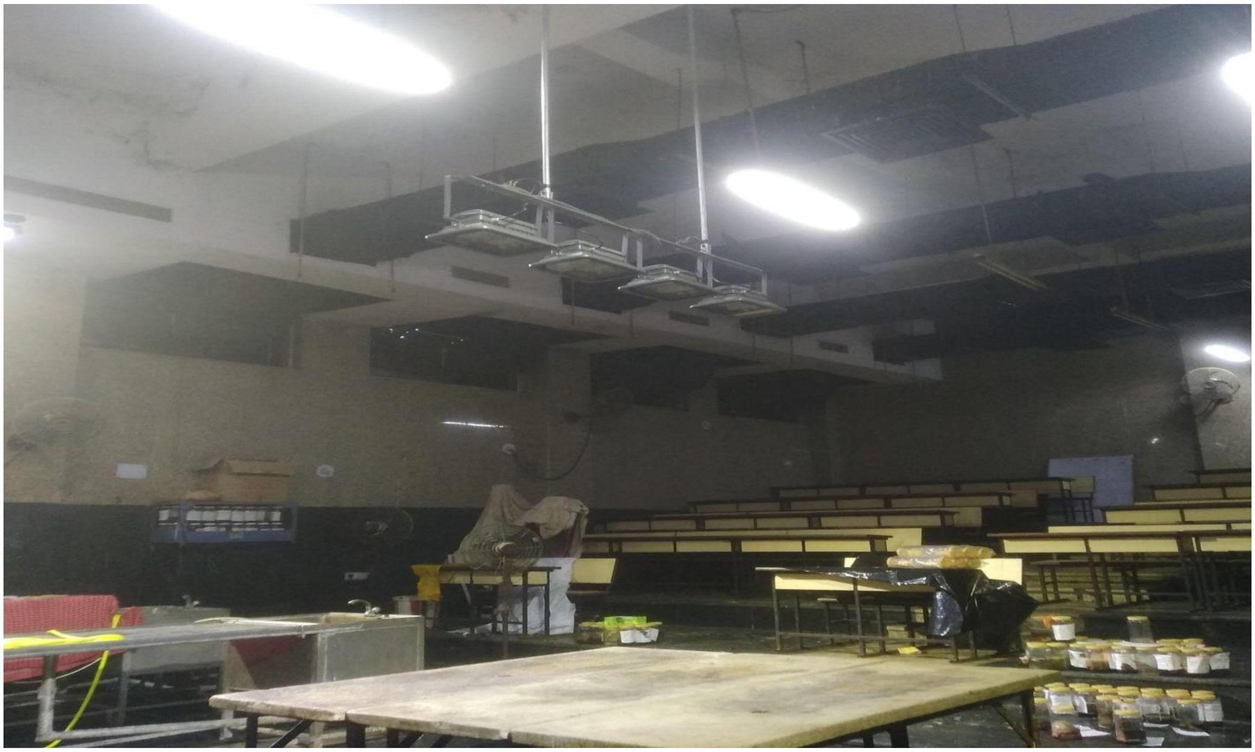


IES R_f VS R_g of Sample-6



SPD of Sample-6

11.6 Output of the Existing system:

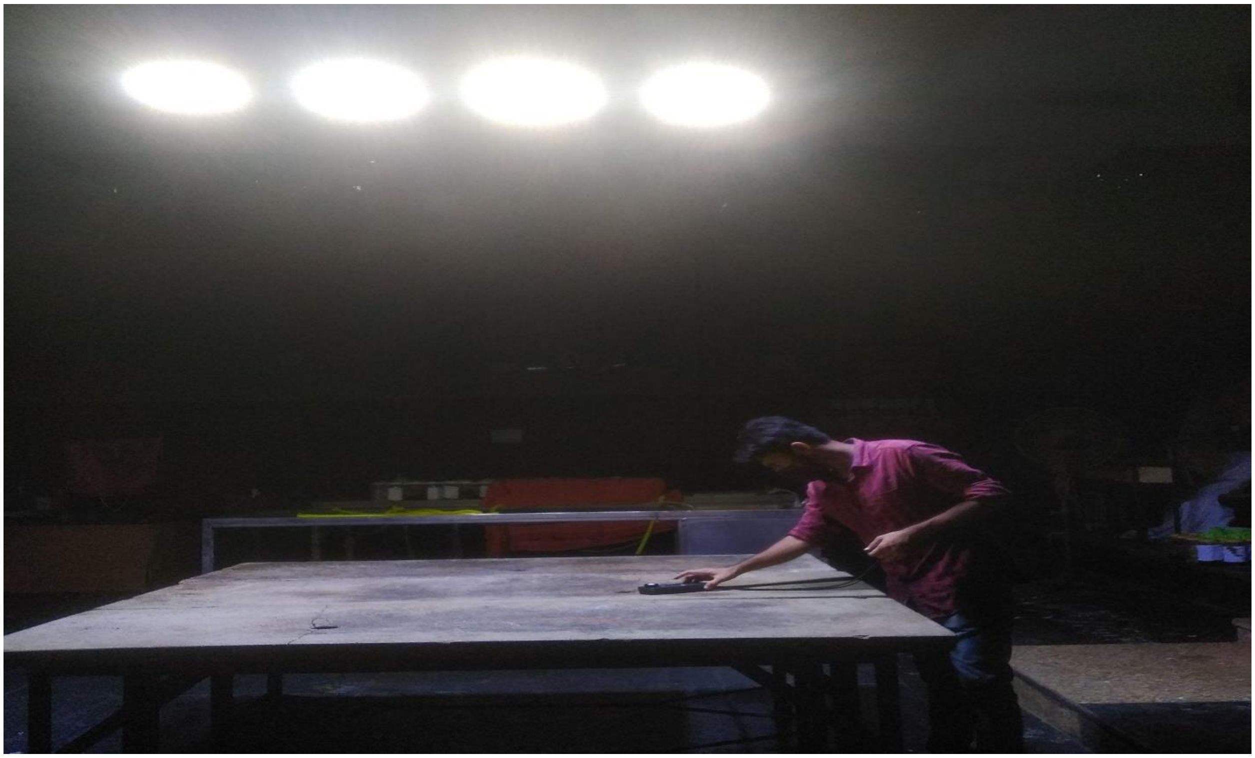


Photometric parameters of Existing system:

E=1480 lux T= 5821K Duv= -0.0018

Ra=77.6 R9= -4.5

11.7 The Case Study using Sample-6 (Developed System):



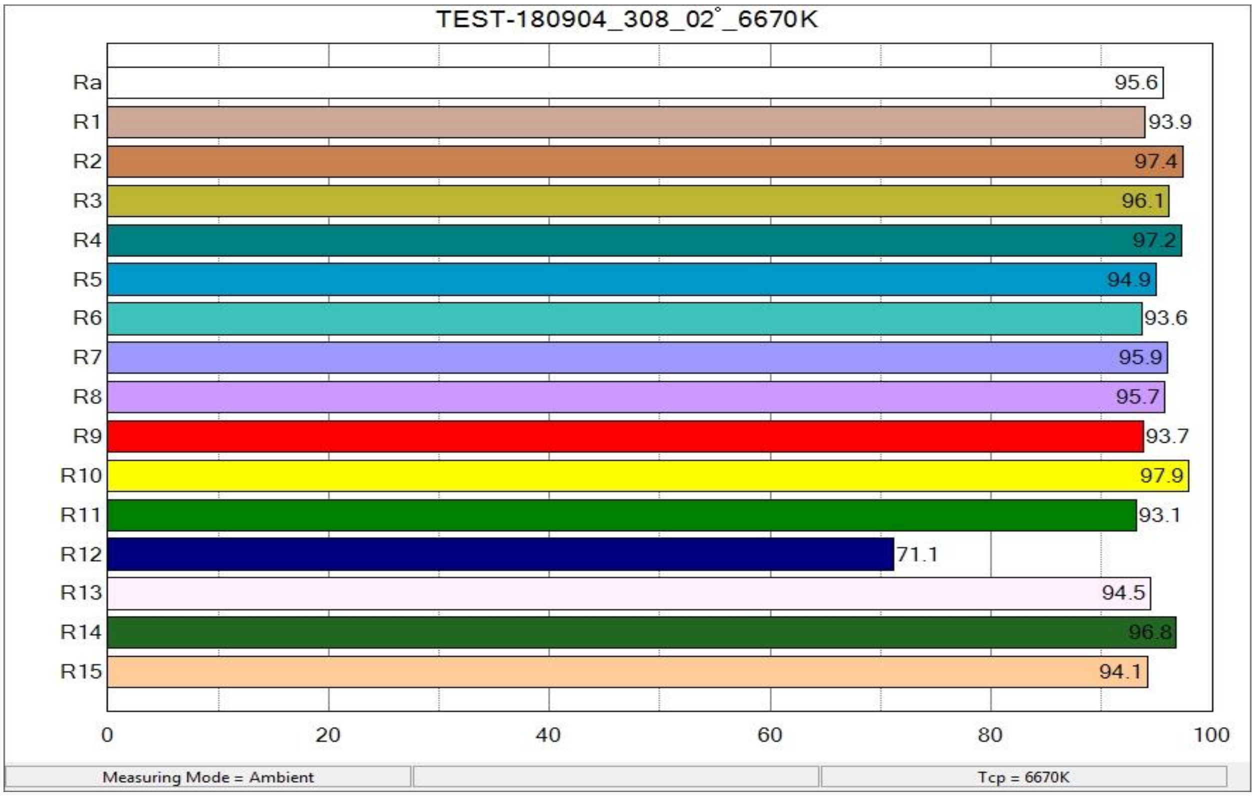
System set up and measurements

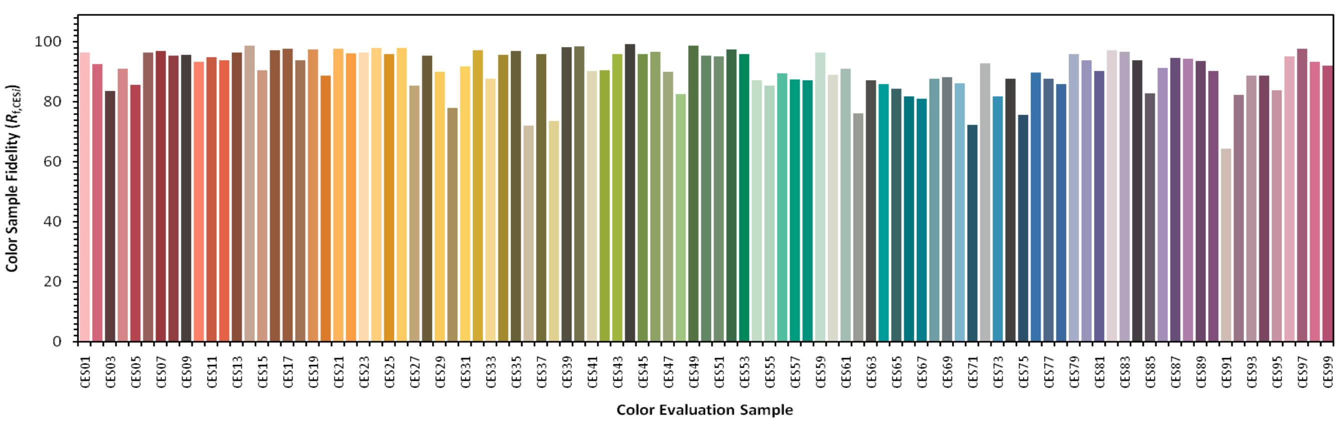
Output using Sample-6 (No greenish or Bluish Spot)

Photometric Parameters of developed system:

E=1680 lux T=6670K Duv= -0.0012

Ra= 95.6 R9= 93.7





99 Color Evaluation Samples (CES) of developed system

1320	1430	1480	1450	1370	1230
1470	1590	1630	1590	1450	1300
1480	1620	1700	1690	1570	1440
1490	1590	1690	1650	1590	1410
1350	1470	1490	1530	1440	1310
1250	1230	1290	1300	1320	1290

Output of the developed system of area 6ft x 6ft

Here **maximum** Illuminance is =**1700 lux** and **minimum** illuminance =**1230 lux**

Average Illuminance =**1458 lux**

Uniformity= **0.84**

CHAPTER 12- CONCLUSIONS:

The design and development of high color quality LED light source with proper CCT by mixing of WW,CW,G,B LEDs for daylight like properties is presented in this thesis.The hardware implementation of the system that is the LED Driver design and the LED arrangements and mixing these LEDs in proper ratios are also been discussed in detail.The measured CRI is more than 95, R9 is more than 92 and CCT is near about 5700K which closely matches the daylight and Duv is also within the tolerance limit as specified by ANSI Standard C.78.377-2008.The design and implementation of a system in practice is more difficult than the design of a single light source.First of all after designing the light source we have taken the IES file of the luminaire and design the system where the critical tasks will be performed in Dialux and according to that we have decided how much luminaire and their arrangement will be done.We have done that experiments and got the proper results.Here we have used lens only in Warm white and cool white but not in green and blue LEDs to avoid the spot of green and blue.So the number of LEDs of green and blue color required is more.So the driver voltage output is also more.To overcome that problem we have used the white LED lens frame (without lens) having some reflectance so the problem has been resolved.The proper LED driver design and proper current rating and controlling of driver current can make the color quality more resembles the daylight at a particular time when the critical tasks can be done.If we can manage a LED lens having a beam angle of more than 120 degree and proper reflector then number of green and blue can be reduced and the ratio of their lux level can be maintained and the required number of luminaire will be reduced.At that time the CRI and R9 both can be more than 96.Here the designed light source having proper color quality but CCT is slightly higher than the normal daylight has.If we can manage to design the proper current and voltage level of the driver then it is possible to make it perfect LED Daylight.

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Appendix

Datasheet of the MOSFET used to Design the LED Driver:

STD6N95K5, STF6N95K5, STP6N95K5, STW6N95K5, STU6N95K5

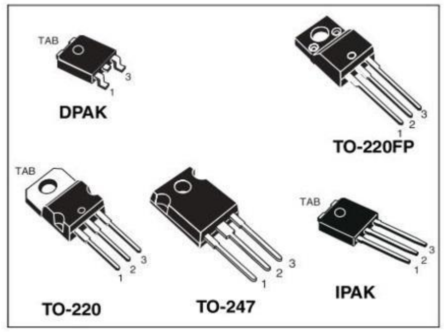
N-channel 950 V, 1 Ω typ., 9 A Zener-protected SuperMESH™ 5 Power MOSFET in DPAK, TO-220FP, TO-220, TO-247 and IPAK

Datasheet — production data

Features

Type	V_{DSS}	$R_{DS(on)}$max.	I_D	P_W
STD6N95K5	950 V	< 1.25 Ω	9 A	90 W
STF6N95K5			9 A	25 W
STP6N95K5			9 A	90 W
STW6N95K5				
STU6N95K5				

- DPAK 950 V worldwide best $R_{DS(on)}$
- Worldwide best FOM (figure of merit)
- Ultra low gate charge
- 100% avalanche tested
- Zener-protected



Applications

- Switching applications

Description

These devices are N-channel Power MOSFETs developed using SuperMESH™ 5 technology. This revolutionary, avalanche-rugged, high voltage Power MOSFET technology is based on an innovative proprietary vertical structure. The result is a drastic reduction in on-resistance and ultra low gate charge for applications which require superior power density and high efficiency.

Figure 1. Internal schematic diagram

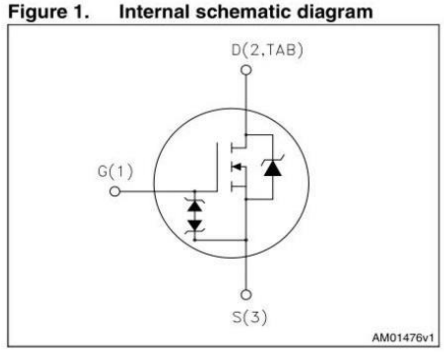


Table 1. Device summary

Order codes	Marking	Package	Packaging
STD6N95K5	6N95K5	DPAK	Tape and reel
STF6N95K5		TO-220FP	Tube
STP6N95K5		TO-220	
STW6N95K5		TO-247	
STU6N95K5		IPAK	

August 2012 Doc ID 16958 Rev 3 1/23

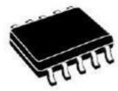
This is information on a product in full production. www.st.com

Datasheet of the IC used to Design the LED Driver:

HVLED001A

Offline controller for LED lighting with constant voltage primary-sensing and high power factor

Datasheet - production data



SSO10

Features

- Quasi resonant (QR) topology
- Optimized output voltage accuracy at any load (PSR mode)
- Improved transient response and startup time
- Direct optocoupler connection for current loop regulation with feedback disconnection detection
- 800 V high voltage startup
- High power factor and low THD over wide range of input voltage and load variations
- High efficiency and output stability over wide voltage and current range
- Low startup and quiescent current
- Programmable minimum off-time
- Integrated input voltage detection for high power factor capability and protection triggering
- Latch-free device guaranteed by smart auto-reload timer (ART)
- 0-10 and PWM dimming compatible
- Remote control pin

Applications

- Single stage LED drivers with high power factor up to 75 W
- Two stages LED drivers up to 150 W

Description

The HVLED001A is an enhanced peak current mode controller capable of controlling high power factor (HPF) flyback or buck-boost topologies in LED drivers that have an output power of up to 150 W. Other topologies, such as buck, boost and SEPIC, can also be implemented.

ST's innovative high voltage technology allows direct connection of the HVLED001A device to the input voltage to start up the device and to monitor the input voltage, without the need for external components.

The device embeds advanced features to control either the output voltage or the output current precisely and reliably using a reduced number of mainly passive components. Startup and light load conditions are managed by dedicated operating schemes to improve the quality of the regulation of the output variable in the final application. Abnormal conditions such as open circuit, output short-circuit, input overvoltage/ undervoltage and circuit failures like open loop and overcurrent of the main switch are effectively controlled.

A smart auto-recover timer (ART) function is built-in to guarantee automatic application recovery, without loss of reliability.

Table 1. Device summary

Order code	Package	Packaging
HVLED001A	SSO10	Tube
HVLED001ATR		Tape and reel

This is information on a product in full production. www.st.com

IES File of the Designed Luminaire:

Lisun Electronics Inc.
http://www.Lisungroup.com
Tel: +86(21)51083341
Fax: +86(21)51083342

Jadavpur University

Page 1 of 56 Pages

Report No.: LED Indoor light for NRS | Test Time: 2023-08-05 15:45

Luminaire Property

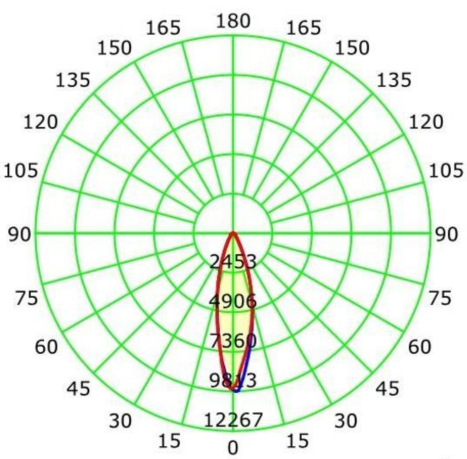
Luminaire Manufacturer:
Luminaire Category: Indoor light | Luminaire Description: LED indoor Light
Lamp Description: 220 V, 0.307 A, 66.97W, PF 0.989
Number of Lamps: 1 | Voltage: 220.5 V
Current: 0.307 A | Power: 67.00 W
Power Factor: 0.989

Photometric Results

CIE Class: Direct | Total Rated Lamp Lumens: 3484.8 lm
Measurement Flux: 3484.8 lm | Efficiency: 100%
Downward Ratio: 100% | Upward Ratio: 0%
Field Angle(C0/C180,C90/C270,C45/C225,C135/315): 57.3, 57.1, 59.5, 59.7
Beam Angle(C0/C180,C90/C270,C45/C225,C135/315): 25.9, 26.5, 27.5, 26.7
Luminaire Efficacy Rating (LER): 52.06 | Central Intensity: 9705.2 cd
Max. Intensity: 9813.62 cd | Pos of Max. Intensity: H0 V1
S/MH(C0/C180): 0.43 | S/MH(C90/C270): 0.43

Picture Of Luminaire

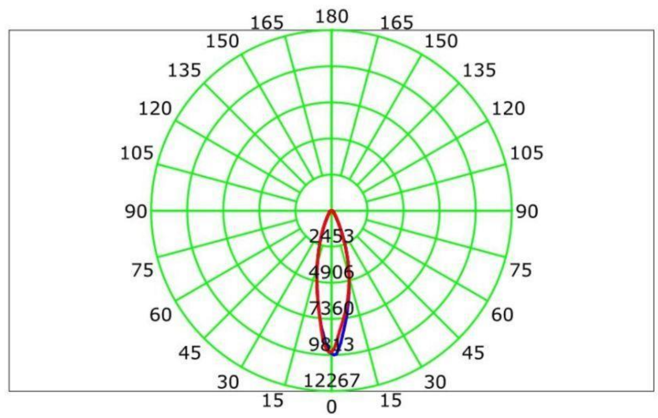
Luminous Intensity Distribution Curve

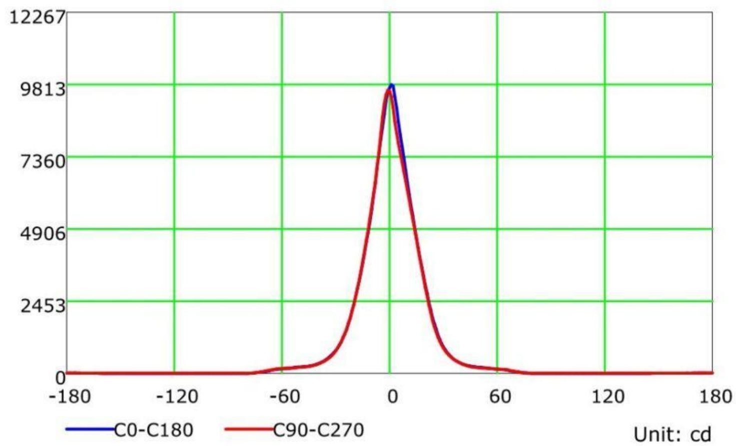


Unit: cd

C Plane (°):0.0-360.0: 5.0 | Gamma Plane (°):0.0-180.0:1.0
Test Lab: Illumination Engineering Laboratory , E | Test Device: LSG-1700B artment , Jadavpur University
Test Type: TYPE C | Distance: 7.470 m
Temperature: | Humidity:
Operator: Kafiur Rahman,ME 2nd Year,Electrical E | Inspector: 2023

Luminous Intensity Distribution Curve

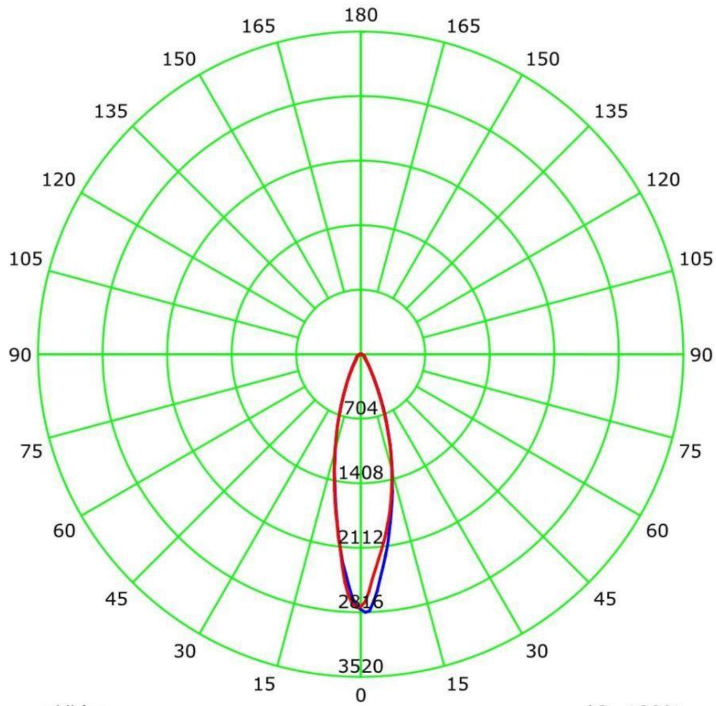




C Plane (°):0.0-360.0: 5.0 Gamma Plane (°):0.0-180.0:1.0
Test Lab: Illumination Engineering Laboratory , ETest Device: LSG-1700Bartment , Jadavpur University
Test Type: TYPE C Distance: 7.470 m
Temperature: Humidity:
Operator: Kafiur Rahman,ME 2nd Year,Electrical EInspector: 2023

Lisun Electronics Inc.
http://www.Lisungroup.com
Tel: +86(21)51083341
Fax: +86(21)51083342

Luminous Intensity Distribution Curve(cd/klm)

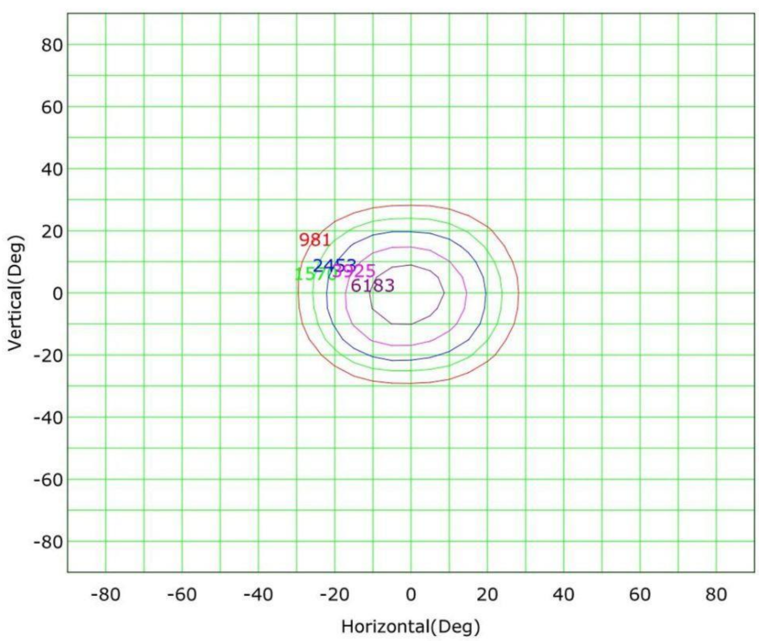


cd/klm
C0-C180
C90-C270

¦Ç=100%
220 V, 0.307 A, 66.97W, PF 0.989

C Plane (°):0.0-360.0: 5.0 Gamma Plane (°):0.0-180.0:1.0
Test Lab: Illumination Engineering Laboratory , ETest Device: LSG-1700Bartment , Jadavpur University
Test Type: TYPE C Distance: 7.470 m
Temperature: Humidity:
Operator: Kafiur Rahman,ME 2nd Year,Electrical IInspector: 2023

Isocandela (rectangle)

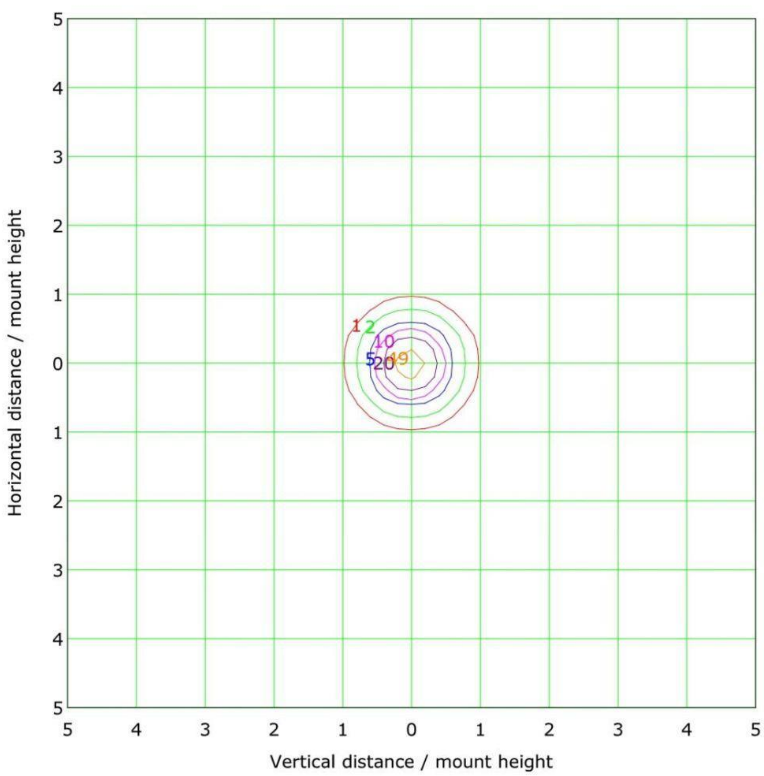


Imax (100%): 9814 cd

(10%): 981 cd
(25%): 2453 cd
(63%): 6183 cd
(16%): 1570 cd
(40%): 3925 cd
(100%): 9814 cd

C Plane (°):0.0-360.0: 5.0
Gamma Plane (°):0.0-180.0:1.0
Test Lab: Illumination Engineering Laboratory , Electrical Engineering Department , Jadavpur University
Test Device: LSG-1700B
Test Type: TYPE C
Distance: 7.470 m
Temperature:
Humidity:
Operator: Kafiur Rahman,ME 2nd Year,Electrical Engineering 2023
Inspector:

IsoLux Plot



Mounting Height: 10.0m Max Lux(100%): 98.1 lx

(1%): 1.0 lx
(2%): 2.0 lx
(5%): 4.9 lx
(10%): 9.8 lx
(20%): 19.6 lx
(50%): 49.0 lx
(100%): 98.1 lx

C Plane (°):0.0-360.0:5.0
Gamma Plane (°):0.0-180.0:1.0
Test Lab: Illumination Engineering Laboratory , Electrical Engineering Department , Jadavpur University
Test Type: TYPE C
Distance: 7.470 m
Temperature:
Humidity:
Operator: Kafiur Rahman,ME 2nd Year,Electrical Engineering 2023
Inspector: