FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail in MS WORD format to eetd@bis.gov.in shall be appreciated.**]

Doc. No.: ETD 49 (25378) P **BIS Letter Ref:** ETD 49/T **Dated:** 24 April 2024

Title: Draft National Lighting Code of India: Part 3 Electric Light Sources & Their Accessories, Section 1 Solid State Lighting (LED Technology), Section 2 LED Driver and Controls [First Revision of SP 72 (Part 3)]

Name of the Commentator/ Organization: ____

Part 3/Section 1 Solid State Lighting (LED Technology)		
Clause No. with Para No. or Table No. or Figure No. commented (as applicable)	**Comments / Modified Wordings**	**Justification of Proposed Change**

Part 3/Section 2 LED Driver and Controls		
Clause No. with Para No. or Table No. or Figure No. commented (as applicable)	**Comments / Modified Wordings**	**Justification of Proposed Change**

April 2024

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

(Not to be reproduced without the permission of BIS or used as a Part of National Lighting Code of India)

Draft NATIONAL LIGHTING CODE OF INDIA

PART 3 Electric Light Sources & Their Accessories

Section 1 Solid State Lighting (LED Technology)

[First Revision of SP 72 (Part 3/Section 1)]

Illumination Engineering and Luminaries Sectional Committee, ETD 49

Last Date for Comments: _____

FOREWORD

In recent decades, the evolution of light sources for general illumination has undergone rapid advancement, particularly with the emergence of solid-state technology. Since 2016, the widespread adoption of LED applications has surged, displacing traditional low-pressure and high-pressure discharge lamps to a significant extent. With LED poised as the primary light source for the future, and given the swift pace of technological development, this chapter focuses primarily on the intricacies and advancements within LED technology.

A snapshot of traditional lighting, including its major applicable specifications, is provided for quick reference to users, facilitating comparison and potential usage scenarios if needed.

This code introduces the Solid-State Lighting (SSL) technology mainly for Light Emitting Diodes (LED).

1 SCOPE

This section provides crucial information necessary to comprehend the typical characteristics of the LED technology for better understanding of LED while manufacturing, user application as well for the specifier community. Although there are concise descriptions of the different construction and performance characteristics of LED technology but the designer should also consult the catalogues /data sheet of individual manufacturers for additional information.

2 REFERENCES

The following Indian standards are necessary adjunct to this section of the code.

IS No.	***Title***
418:2005	Tungsten filament general services electric lamps
2418(Part 1):1977	Tubular fluorescent lamps for general lighting services: Part 1 Requirements and tests
9900 (Part 1):1981	High pressure mercury vapour lamps: Part 1 Requirements and test
9974 (Part 1) : 1981	High pressure sodium vapour lamps: Part 1 General requirements and test
12948:1990	Tungsten halogen lamps (non vehicle)
15111 (Part 2): 2002	Self-ballasted lamps, Part 2 Performance requirements

3 TERMINOLOGY

The definitions of the terms used in this chapter are given in Part 1 of this code.

4 CLASSIFICATION OF LAMPS

4.1 General

The electric light sources technology can be classified according to their primary operating principle (*see* Fig. 1).

a) Incandescent lamps: These emit light through a heated metal filament. The halogen lamp contains a special vapour that enhances its effectiveness. Due to their low effectiveness, these types will be phased out in the future;
b) Gas Discharge Lamps: The light from these lamps is produced by a discharge between two electrodes in a glass or ceramic tube fil LED with a gas. There are two ranges based on the most significant gas: sodium or mercury. High or low pressure in the glass tube can subdivide either of these ranges; and
c) LEDs are semiconductor devices. When a current flow through an LED, electrons combine with electron holes, releasing energy as light. In the process, "extra" energy is released as light. Using a variety of semiconductor materials and manufacturing processes, the light's wavelength (and consequently its colour) can be altered to suit. In addition, the wavelength spread of the emitted light is comparatively narrow, resulting in colours that are pure (or saturated).

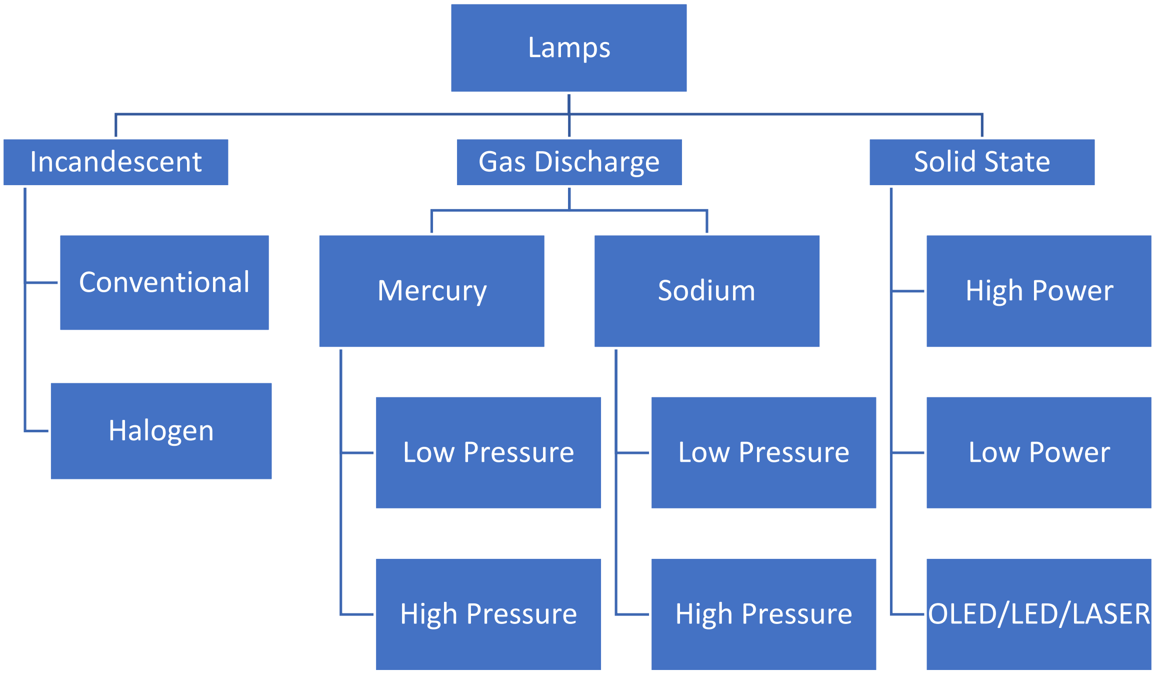


Fig. 1 Broad Classification of Lamps

Table 1 given the board characterises of all electric light sources. This enables the user and specifier to select the right combination. It is obvious that LED light sources are winning the selection criteria in most applications of general lighting. Hereafter this chapter is dedicated for LED technology with respect to light source

Table 1 Characteristics of Different Light Sources

S.NO	**Light Source**	**Wattage Range (W)**	**Efficacy (lm/W)**	**Life (h)**	**Lumen. Maintenance %**	**Starting Time in Second**	**Colour Rendition Ra**	**Dimming Capability**	**Colour Temp K**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1.	Incandescent	15 to 150w	8-to 12	500 to 1,000	50 to 65%	Instant	100 Excellent	Excellent	2700
2.	Low Voltage Halogen	1to 30	12 to 20	1000 to 2,000	50 to 75%	Instant	100 Excellent	Excellent	2700 to 3000
3.	Mains voltage Halogen	300 to 1500	20 to 27	200 to 2,000	50 to 60%	Instant	100 Excellent	Excellent	3000
4.	Fluorescent T8 & T8 Tri-Phosphor	18 to 80	60 to 90	5,000 to 15,000	60 to 85%	3 to 10	60 to 88	Possible	2700 to 65000
5.	Fluorescent T5	14 to 58	80 to 105	10,000 to 20,000	80 to 90%	3 to 10	80 to 98	Possible	2300 to 6500
6.	Compact Fluorescent Integral (retrofit)	5 to 180	60 to 85	5,000 to 15,000	65 to 85%	2 to 5	65 to 85	Very Low	2300 to 6500
7.	Compact Fluorescent Non-Integral (2pin & 4 pin)	5 to 120	60 to 85	5,000 to 20,000	65 to 85%	2 to 5	70 to 90	Possible	2300 to 6500
8.	Blended Light	160 to 250	20 to 30	3,000 to 5,000	55 to 65%	Instant	85 to 95	Very Low	3500 to 5000

9.	Metal Halide	35 to 2000	80 to 95	4,000 to 12,000	60 to 85%	240 to 480	70 to 95	Up to 40%	2700 to 4500
10.	High Pressure Sodium	50 to 1000	90 to 125	10,000 to 32,000	70 to 88%	120 to 360	20 to 28	Up to 40%	2000 to 3000
11.	Low pressure Sodium Sox	10 to 180	65- 100 to 220	8,000 to 15,000	80 to 90	120 to 240	Negative Mono-chromatic	Not recommended	2400 to 3500
12.	Induction lamp	10 to 160	66- To 80	8,000 to 15,0000	60 to 75%	Instant	75 to 85	Not commended	32000 to 5500
13.	Single LED white	0.5 to 5	60 to 180	10,000 to 1,00,000	60 to 95%	Instant	60 to 95	Excellent	2700- to 10000
14.	LED system white	2 to 8,000	70 to 160	10,000 to 75,000	60 to 95%	Instant	60 to 95	Excellent	2701- 2 700 to 10000
15.	OLED	0.5 to 60	40 to 80	10,000 to 40,000	85 to 95%	Instant	60to 95	Excellence	2702- 2 700 to 6500

Table 2 Characteristics /Specification for Incandescent, Low Pressure and High Pressure and Induction Lamps

S.No	**Name**	**Optical spectrum**	**Nominal efficiency (lm/W)**	**Lifetime (MTTF) (hours)**	**Color temperature (kelvin)**	**Color**	**Color rendering index**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.	Incandescent light bulb	Continuous	4-17	2-20000	2400-3400	Warm white (yellowish)	100
2.	Halogen lamp	Continuous	16-23	3000-6000	3200	Warm white (yellowish)	100

3.	Fluorescent lamp	Mercury line + Phosphor	52-100 (white)	8000-20000	2700-5000*	White (various color temperatures), as well as saturated colors available	15-85
4.	Metal halide lamp	Quasi-continuous	50-115	6000-20000	3000-4500	Cold white	65-93
5.	Sulfur lamp	Continuous	80-110	15000-20000	6000	Pale green	79
6.	High pressuresodium	Broadband	55-140	10000-40000	1800-2200*	Pinkish orange	0-70
7.	Low pressure sodium	Narrow line	100-200	18000-20000	1800*	Yellow, no color rendering	0
8.	Light-emitting diode	Line plus phosphor	10-110 (white)	50,000-100,000	Various white from 2700 to 6000*	Various color temperatures, as well as saturated colors	70-85 (white)
9.	Induction Lamp (External Coil)	Mercury line + Phosphor	70-90 (white)	80,000-100,000	Various white from 2700 to 6000*	Various color temperatures, as well as saturated colors	70-85 (white)

5 LIGHT EMITTING DIODES (LED)

LEDs are semiconductor diodes that allow current to flow in a single direction. The diode is formed by bringing two slightly different materials together to form a "PN" junction. A pn junction is characterised by an excess of positive charge in the p-type region, represented by holes, and an excess of negative charge in the n-type region, represented by electrons.

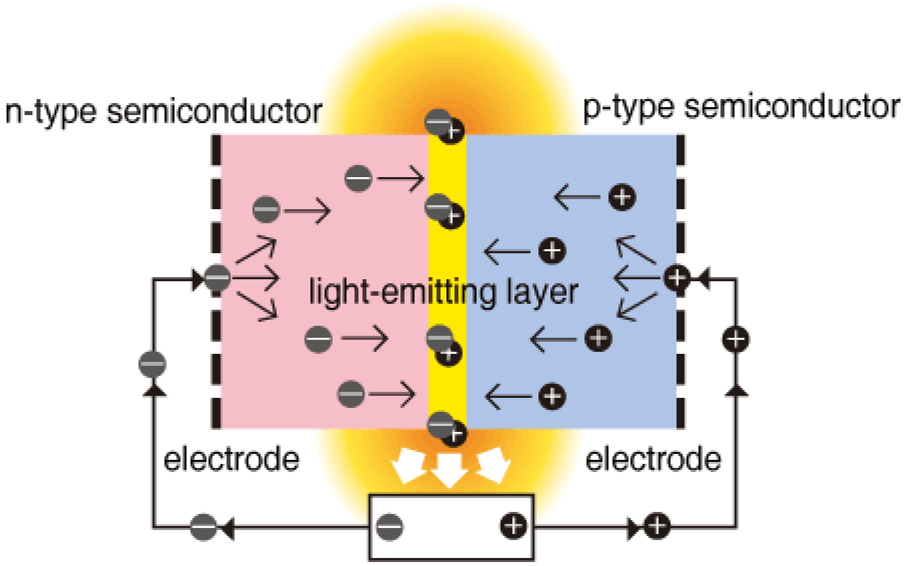


Fig. 2 LED Operation

Upon application of a forward voltage to the semiconducting element forming the 'pn' junction, electrons and holes migrate towards the 'p' and 'n' regions, respectively. Electrons and holes recombine in the vicinity of the junction. During this process, the LED emits light as a result of energy release (refer to Fig. 2). LED devices have a maximum reverse voltage specified by manufacturers, typically rated at 5 V.

Fig 3 depicts the standard voltage-current correlation for an illumination-grade LED. The figure illustrates that a small alteration in voltage can lead to significant variations in current. LED light output can vary significantly due to the proportional relationship between current and light output.

Exceeding the recommended current limits by the manufacturer can negatively impact the long-term performance of the LED, leading to a shorter useful life. The solid line in Figure 3 represents the standard operating parameters, while the dotted lines indicate extrapolation.

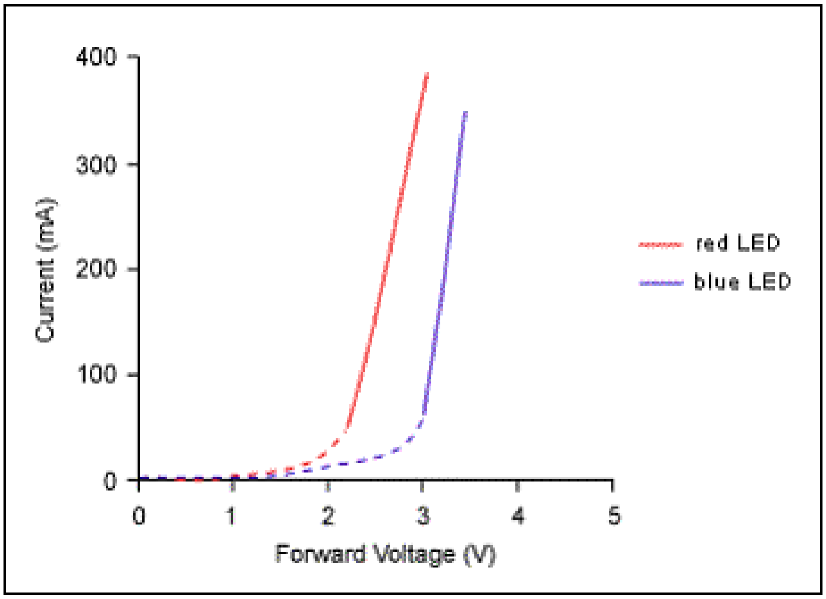


Fig. 3 The Relationship Between Forward Voltage And Current For Illuminator LEDs

An LED driver serves a function akin to that of a ballast for discharge lamps. It regulates the LED's current. LED drivers are typically designed to provide current to a specific device or array. Matching the driver to the specific LED package or array is crucial due to the lack of standardisation in these components.

Several material technologies are available to make an LED. LED materials are III-V materials that possess a vacancy for an electron, a hole, or a single electron in the outermost shell of the atom. The material used in the semi-conducting element of an LED determines its colour. GaP and AlGaAs are legacy technologies. These technologies enable the production of wavelengths ranging from red to yellowish-green, primarily serving as indicators and illuminating keypads and instrument clusters in the automotive and computer sectors. The drawback of these technologies is that the LEDs' lifespan decreases notably under elevated temperatures and currents. The production of these LEDs is cost-effective.

AlInGaP was introduced as a material system capable of withstanding high currents and humidity, thereby overcoming the aforementioned disadvantages. This technology underlies the development of high-brightness red and amber LEDs.

InGaN technology was first introduced by Mr. Nakamura at Nichia in the early 1990s. This technology introduced the initial blue, green, and cyan light-emitting diodes (LEDs). Later, white LEDs appeared on the market. All colours were present except for pure yellow.

This opened the road for many applications: Traffic signals, such as the green signal. RGB-based large screens White light sources such as torches and cell phone screens with white backlights are commonly used for general illumination purposes.

At this moment, two technologies are leading in the field of high-brightness LEDs: AlInGaP and InGaN. Various types of LEDs are available, and their performance characteristics can differ widely.

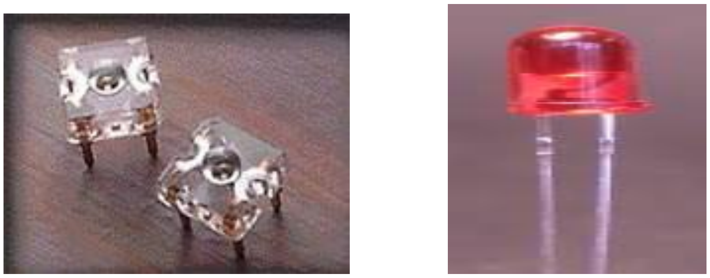


Fig.4 Through Hole LEDs

Through-hole LEDs are considered the conventional type of LED. The package leads are inserted through a hole in the PCB, hence the name "through hole (fig4). These are available in diameters of 3.4 and 5mm and are used in diverse applications. The product comprises a lead frame and an epoxy housing that serves as the primary lens. The range of typical currents is 20–50 mA. The enhanced variant, referred to as the Superflux LED, has the capacity to manage a maximum of 70 mA.

This product is commonly used in the automotive and signage sectors. Generating lumens ranging from several to 10 lm. SMDs were developed due to the challenging nature of achieving high yields in the automatic placement of these LEDs. SMD LEDs, also known as surface-mount LEDs, are used in various applications such as instrument clusters in automobiles, car radios, backlighting for mobile phone screens, keypad illumination, and computer indicators. It can be mounted and soldered onto a PCB using standard automatic placement and in-line soldering equipment. The LEDs are mounted on a PCB and subjected to a high-temperature oven or a wave of melted solder for soldering. The range of typical currents is from several mA to 150 mA. The luminance ranges from less than 1 lm to 10 lm. These LEDs are suitable for high-volume production.

High-power LEDs have facilitated the integration of the semiconductor industry and general lighting. These LEDs were the first to illuminate due to their superior optical and thermal properties. A thermal and optical design is required to optimise the potential of the LEDs. LEDs can produce over 200 lm with current ranges between 350 mA and 1500 mA.

The characteristics of LEDs can be categorised into optical, thermal, and electrical performance, as well as various methods of LED driving. Like other light source technologies like fluorescent and high-intensity discharge, LED lighting systems consist of a light source (usually individual LED sources), a driver (commonly referred to as a driver for LEDs), and a luminaire (which includes materials surrounding the light source for optical and thermal control of the system).

LED lighting systems are expected to incorporate numerous individual light sources in the near future, in contrast to traditional systems that typically have one to four light sources. Several commercially available arrays are depicted in Fig. 5.

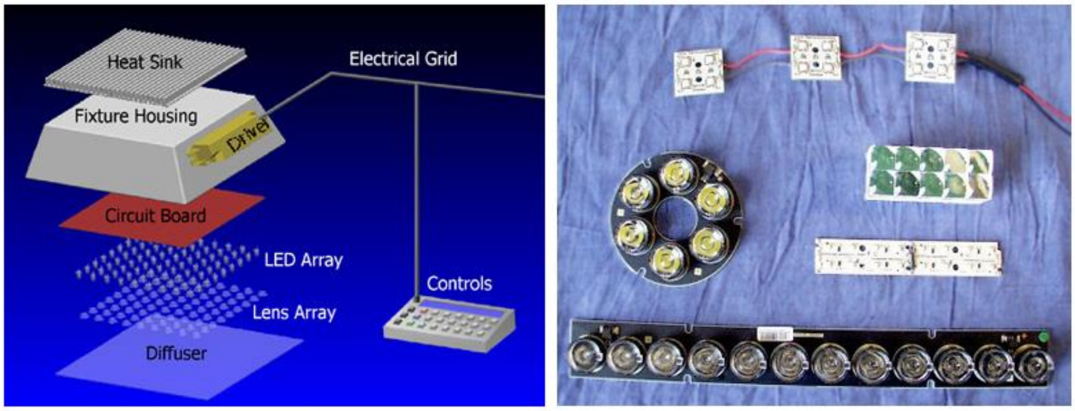


Fig. 5 LED Array

Solid-state lighting (SSL) refers to a group of light sources, such as semiconductor LEDs, organic OLEDs, and polymer PLEDs, that utilise solid-state electroluminescence. LEDs utilise injection luminescence, the most efficient form of electroluminescence, to produce light.

6 LED A LIGHT SOURCE

The discovery of blue LEDs elevated the functionality of LEDs from that of mere indicators to that of illuminators. The PCLED, which is a blue LED chip coated with yellow-emitting phosphor, is capable of producing white light. This process is highly suitable for automation, thereby rendering the LEDs cost-effective for widespread adoption.

Currently, LEDs are the most efficient SSL light sources that can be easily customised to various specifications such as colour, hue, colour fidelity, brightness, spectral distribution, and spatial beam distribution. Additionally, they can be dimmed and colour-tuned. LEDs are durable, small in size, and have a significantly long lifespan.

White LEDs with different shades, as well as monochromatic LEDs, can be produced using various phosphors. (Fig. 6)

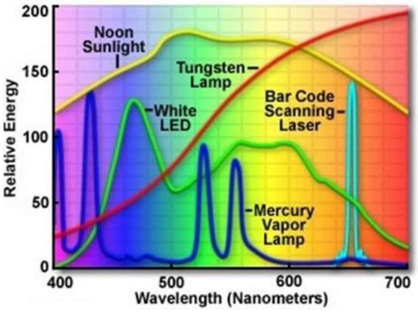


Fig.6 Various Sources of Light Seen w.r.t Their Spectral Power Distribution.

PCLEDs fulfil the desired criteria for an optimal light source in terms of efficiency, lifespan, and durability. In contrast to fluorescent lights, LEDs are environmentally friendly as they do not contain any hazardous chemicals or mercury. LED technology is widely used for general, domestic, industrial, and automotive lighting.

The rapid improvements in the LED capability is given in the DOE research road map below:

Table 3 Proposed Efficacy Chart of LED

High Efficacy LED Prototypes

Description: Demonstrate novel package integrations schemes that focus on improved epitaxy, phosphors, optical performance, and electrical efficiency to surpass DOE SSL Program interim efficacy targets and accelerate achievement of ultimate DOE SSL goals. Furthermore, LEDs should enable advanced luminaire performance to meet target by integrating luminaire functionality into prototype LED concepts. Advanced features such as optical components that can shape the beam or mix the colored outputs from LED sources evenly across the beam pattern are encouraged, along with novel thermal handling and electrical integration while also advancing efficiency.

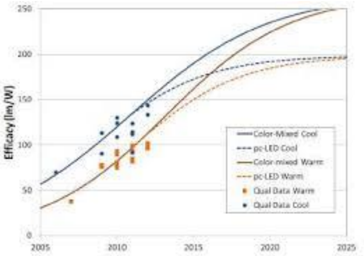
Metrics	2016 Status	Interim 2020 Targets	2025 Targets
Luminaire Efficacy	Approx. 140 lm/W Depends on CCT, CRI, beam angle, luminance distribution, etc.	200 lm/W	225 lm/W

As on 2020 it is observed that commercially value achieved as proposed by scientists.

7 THE LEDS - A SUPERIOR TECHNOLOGY

LEDs exhibit high durability. The absence of fragile glass or filament eliminates the risk of breakage. The chip is a solid cube. The chip and gold wire connections are protected by putting them in silicon, which enhances their mechanical durability.

LEDs have the highest efficacy of lumens per watt among all known light sources, as they efficiently convert electrical power to light. Incandescent bulbs have a luminous efficacy of 12 lumens per watt. Only 3% of the power is converted into light. CFLs and tube lights have an efficacy of 60-80 lumens per watt. Commercially available LEDs typically produce 120-170 lumens per watt, while laboratory demonstrations have shown up to 300 lumens per watt.



.

Fig. 7 Time Line of Efficient Sources of Light -Conventional Versus LEDs.

LEDs exhibit a lifespan exceeding 100,000 hours. This can be compared to 1000 hours of incandescent bulb usage and twice that amount for a tube light. The biggest advantage of LED is absence of mercury. CFLs and FTLs, commonly known as energy-efficient lighting options, contain small amounts of mercury, typically measured in milligrams. Trillions of these lamps dumped in landfills create highly toxic planet for the future generations.

The use of LEDs has raised concerns regarding the potential long-term effects of blue emission on the retina and the suppression of melatonin, which is essential for regulating the sleep cycle. Use of warmer whites with less-blue LEDs, promoted through consumer education, is a ready remedy. Refer the Part 15 of NLC for blue light hazards.

7.1 Working Principle

Already stated beginning of the chapter but here more details. Ref Fig 8 for photoemissions in LEDs. When an LED is powered, the electrons within the material absorb the electrical energy and transition to a higher energy level. Since it is not their natural state, they tend to fall back to the natural orbit level. The absorbed kinetic energy is primarily emitted as photons. A portion of the recombination process in LEDs is non-radiative and results in heat dissipation. This phenomenon is associated with the Lumen Efficacy of the LED structure. The photon's colour is determined by the electron bandgap of the material utilised in the p-n junction diode.

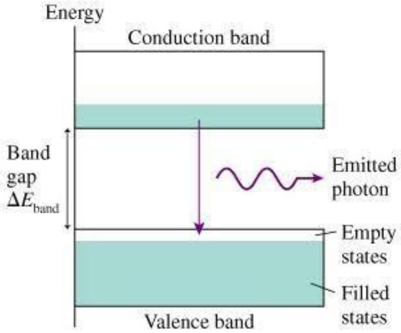
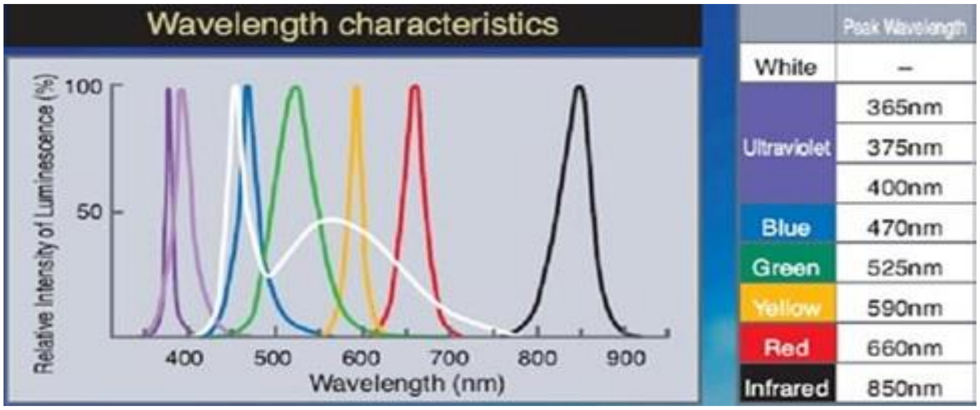


Fig 8. Photoemissions in LEDs

The electron band gap for the human visible range occurs only in materials made with III-V compounds. Within the visible band, the emission colour is decided by the ratio of compounds GaN-InN, AlP-InP-GaP, and AlAs-GaAs that are built by a slow deposition process called MOCVD (Metal Organic Vapour Phase Deposition) on sapphire and silicon carbide substrates. The latter has eight times more thermal conductivity than the former. The initial layers of a p-n junction LED consist of lattice matching layers, multiple p-doped and n-doped quantum wells, current spreading layers, ohmic matching layers, and transparent electrodes.

Many emerging technologies for the emission of light are being researched (Fig. 9 common LED spectra) like micro LEDs, quantum dots, and nanotube structures.



	Peak Wavelength
White	–
Ultraviolet	365nm
	375nm
	400nm
Blue	470nm
Green	525nm
Yellow	590nm
Red	660nm
Infrared	850nm

Fig. 9 Common Color Spectra in LEDs

Semiconductor materials used for producing different Colours are listed in Table 4

Table 4 LED Materials and Emission Colors

Aluminium Nitride (AlN)	**Aluminium Gallium Nitride (AlGaN)**
Aluminium Gallium Indium Nitride (AlGaInN)	**Indium Gallium Nitride (InGaN)**
Silicon Carbide (SiC)	**Aluminium Gallium Indium Phosphide (AlGaInP)**
Gallium Phosphide (GaP)	**Gallium Arsenide Phosphide (GaAsP)**
Aluminium Gallium Arsenide (AlGaAs)	**Gallium arsenide (GaAs)**

WAVELENGTH	**COLOUR**	**VF @ 20MA**	MATERIAL
< 400	Ultraviolet	3.1 - 4.4	AlN, AlGaN, AlGaInP
400 - 450	Violet	2.8 - 4.0	InGaN
450 - 500	Blue	2.5 - 3.7	InGaN, SiC
500 - 570	Green	1.9 - 4.0	AlGaP, AlGaInP, GaP
570 - 590	Yellow	2.1 - 2.2	AlGaInP, GaP
590 - 610	Orange / Amber	2.0 - 2.1	GaAsP, AlGaInP, GaP
610 - 760	Red	1.6 - 2.0	AlGaAs, GaAsP, AlGaInP, GaP
> 760	Infrared	< 1.9	GaAs, AlGaAs, InP

7.1.1 *External Quantum Efficiency for InGaN and AlInGaP LEDs*

Current knowledge of material science results in unequal external quantum efficiency at different wavelengths.

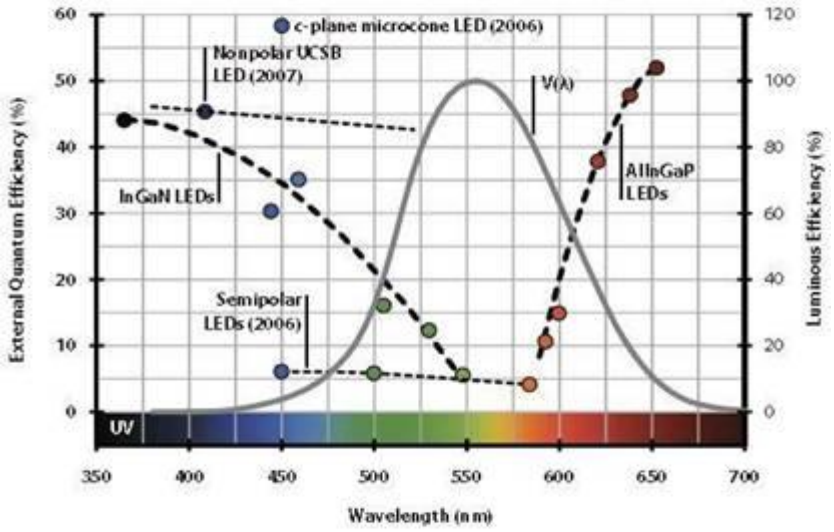


Fig. 10 Wavelength (nm) vs External Quantum Efficiency (%) for InGaN and AlInP LEDs

The external quantum efficiency Fig 10 of non-polar UCSB LED (2007) decreases slightly as wavelength increases. The external quantum efficiency of InGaN LEDs decreases as wavelength increases. The external quantum efficiency of Semipolar LEDs (2006) experiences a slight decrease as wavelength increases. The external quantum efficiency of AllnGaP LEDs exhibits a significant increase as the wavelength increases.

7.2 Manufacturing Process of White LEDs

The LED chip is selected based on the required power capacity and then attached to the desired package size using the die attach process. The Wirebond process involves using 25-micron Gold, Alloy, or Copper wires to thermosonically bond electrode pads of a chip to package terminals. The phosphor is uniformly dispersed in silicone using a vacuum centrifugal mixer, and then accurately deposited onto the LED chip located in the reflector lead frame. The mixture is subsequently thermally cured. The LEDs undergo a 100% testing process and are automatically sorted into specific groups based on their colour (CCT, XY values), lumens (L_m), and forward voltage (V_f) combinations.

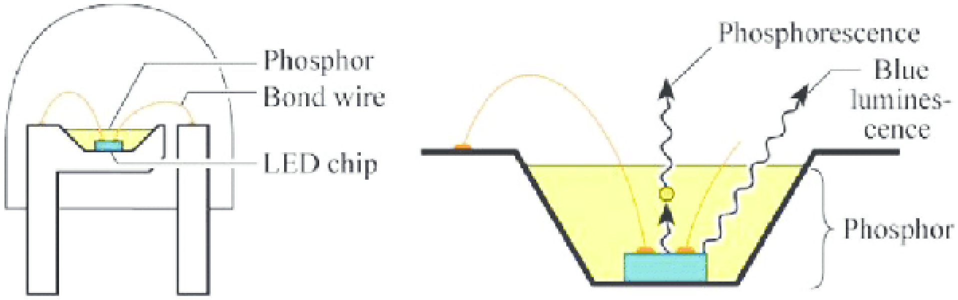


Fig.11 LED Internal Structure

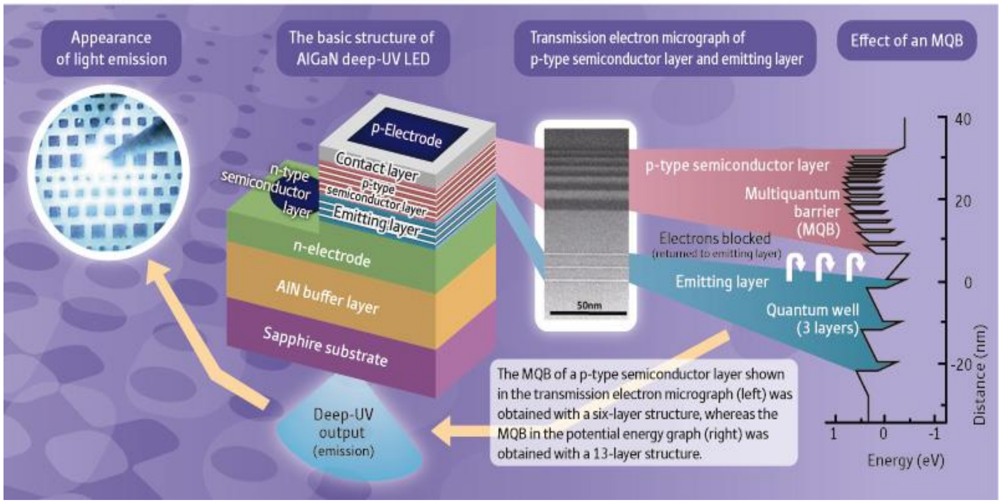


Fig. 12 Complex Structure of Multiple Quantum Wells & Epilayers of Lattice Matching, Current Spreading & Light Extraction Inside A LED Die.

There are three main methods of mixing colours to produce white light from an LED ref below fig 13.

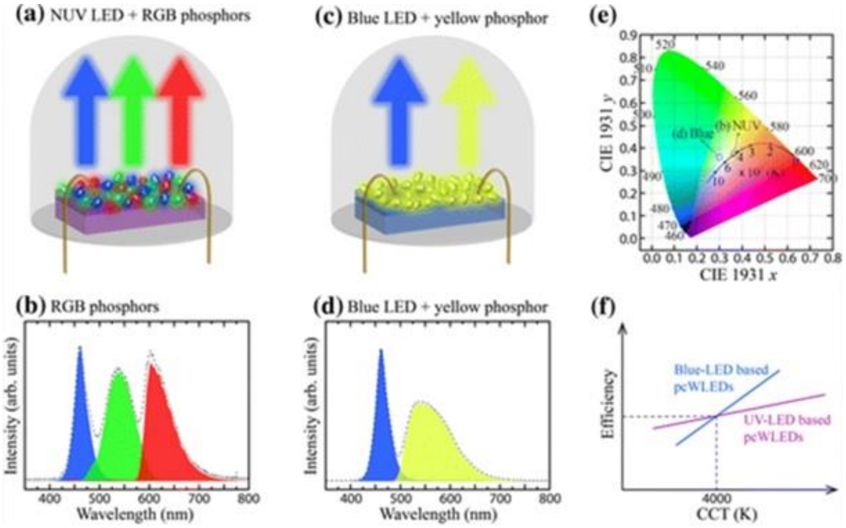


Fig. 13 Colour Mixing Of LEDs

- Red LED + Green LED + Blue LED (colour mixing as in active displays).
- Near-UV or UV LED + RGB phosphor (as in Fluorescent Tubes).
- Blue LED + yellow phosphor – (mixing two complementary colours)

The blue chip is selected as a source due to its high efficiency in blue emission. Applying a phosphorus coating to the chip can transform a portion of the blue energy into yellow. By regulating the phosphor quantity, we can achieve net emission in the form of cool white (6000K

CCT), neutral white (4500K), or warm white (3000K). Increasing the amount of red and green phosphor enhances the LED light's colour rendering index (CRI) and produces a more comprehensive range of colours.

The phosphor types are YAG, TAG, silicates, nitrates, etc. doped with rare earths like Ce, Eu, Tb/Dy etc., giving us a wide choice of emission peaks to achieve any desired colour.

8 ANATOMY OF MODERN LEDS & COMMON LED TYPES AND PACKAGES (Ref (Fig. 14)

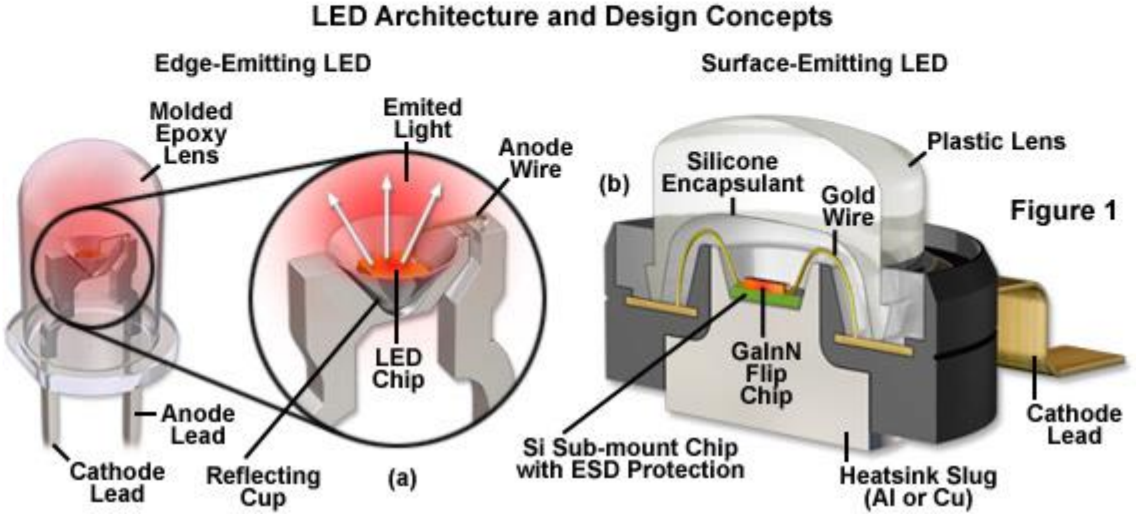


Fig. 14 Inside the LED - Lead frame, Chips & Encapsulant

Distinguishing LED packages from LED luminaires can be challenging due to the similarity in appearance between SSL products and both light sources and luminaires.

A LED array is a collection of LED packages on a printed circuit board or substrate, which may include optical elements and other thermal, mechanical, and electrical interfaces. The device lacks a power source, an ANSI standardised base, and direct connection to the branch circuit.

A module consisting of one or more Light Emitting Diodes (LEDs). An LED module comprises one or more LEDs that are linked to the load side of an LED power source or driver. An LED module may include electrical, electronic, optical, and mechanical components. The LED module lacks a power source and is not directly linked to the branch circuit.

8.1 Direct View Application refers to a lighting design application that involves lamps and/or luminaires that are specifically intended to be viewed directly, rather than being used for general illumination purposes. Illustrative instances comprise sparkle effects, navigational markers, and media walls.

8.2 LED Packaging.

A LED package is comprised of one or more LED dies, wire bond connections, and may include an optical element, as well as thermal, mechanical, and electrical interfaces. The device lacks a power source, an ANSI standardised base, and direct connection to the branch circuit.

LED packages lack a standardised nomenclature for ordering or characterising. To communicate relevant characteristics, multipage data guides are necessary. These characteristics include physical size, maximum ratings for DC forward current, maximum permissible peak forward current, maximum LED junction temperature, reverse voltage limit, operating and storage temperature ranges, and minimum, typical, and maximum forward voltages. LEDs are categorised into bins based on their radiant flux and dominant wavelength, which must be specified in relation to a DC forward current. The cut sheet may also provide plots of wavelength shift versus forward current, relative output versus forward current, SPDs, and a polar plot of luminous intensity. Operational data is temperature-sensitive and data guides usually rely on a 25°C ambient temperature.

8.3 LED Luminaires

This is a comprehensive LED lighting system that includes a light source, driver, light distribution components, protective housing for the light source, and connection to a branch circuit.

LED package data is significant for luminaire manufacturers who integrate packages into LED luminaires. LED package data is relevant to lighting specifications as the design application can influence the characteristics of the LED package. The manufacturer of LED packages or LED luminaires cannot regulate ambient temperature. Effective utilisation of LEDs necessitates optimal integration among the LED package, LED luminaire, and design application.

Fig.15 LED Package types - DIP, Power, SMD COB, Filament LEDs

8.4 DIP LED

DIP(Dual In Package) LEDs, also known as through-hole LEDs, feature axial leads made of silver or tin-plated iron and a chip enclosed in durable epoxy. The beam angle of an epoxy lens can vary from 8 to 140 degrees, depending on the lens shape and chip positioning. Typically, these devices possess a 20 mA rating and are available in bipolar (2 leads), bicolor (3 leads), and tricolour (4 leads) leadframe configurations. The LED chip can be configured for plug-and-play either with an IC for RGB flashers or with an embedded resistor. DIP LEDs are commonly used as indicators of status and in mobile signage.

8.5 SMD Chip

SMD, Surface Mount Device LED, have small footprint and also a thermal path through a inner heat slug, copper or metal alloy base, injection molded body of PPA (0.2W, 0.5W), or PCT (1W) or EMC (1W above). SMD can be Multiple Chips and Multiple terminals type. SMD are made for fast automated electronic assembly.

8.6 COB Chip

Chip on Board (COB). COB refers to a technology in which multiple electronic components are mounted on a single substrate, resulting in a compact and efficient design. The defined light emitting surface houses several diode chips. The design of optics considers COB as a singular point source. It mitigates the nuisance of multiple shadows that are linked to LED arrays. COBs achieve high light spatial density. However, improved thermal management is required for the concentrated heat produced. Chip-on-board (COB) technology eliminates the requirement for printed circuit boards (PCBs), reduces the necessity for costly surface-mount technology (SMT) soldering lines, and streamlines the production of LED lighting. Reflector optics are typically preferred for spot lights, while lens optics are commonly used for outdoor lights.

8.7 Flip Chip LEDs & CSP LED

In Flip Chip version the electrode pads & thermal pads are expanded and at same plane, allowing direct solder to the PCB. FC LEDs can be coated with Phosphor individually through a process cal LED CSP – Chip Scale Packaging. Shown in Fig. 16 & Fig. 17.

8.8 Filament LED

The need for retrofit for chandeliers and squirrel cage bulbs, gave birth to filament LEDs on narrow strips weldable like classic tungsten filaments.

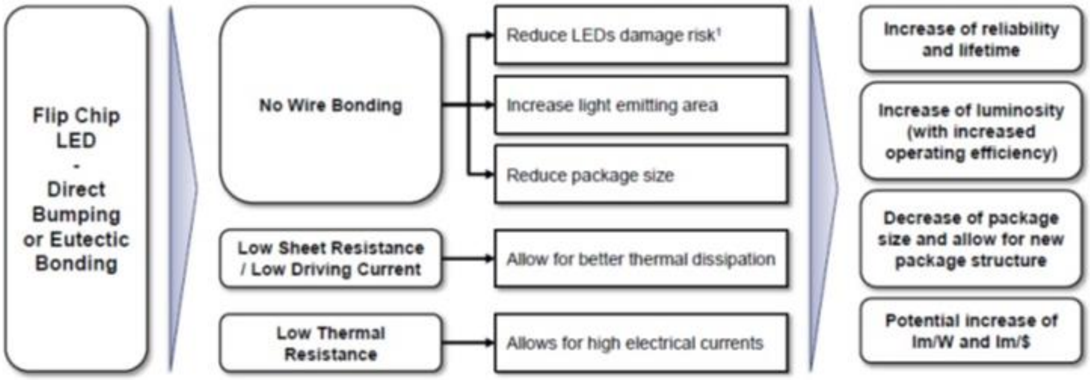
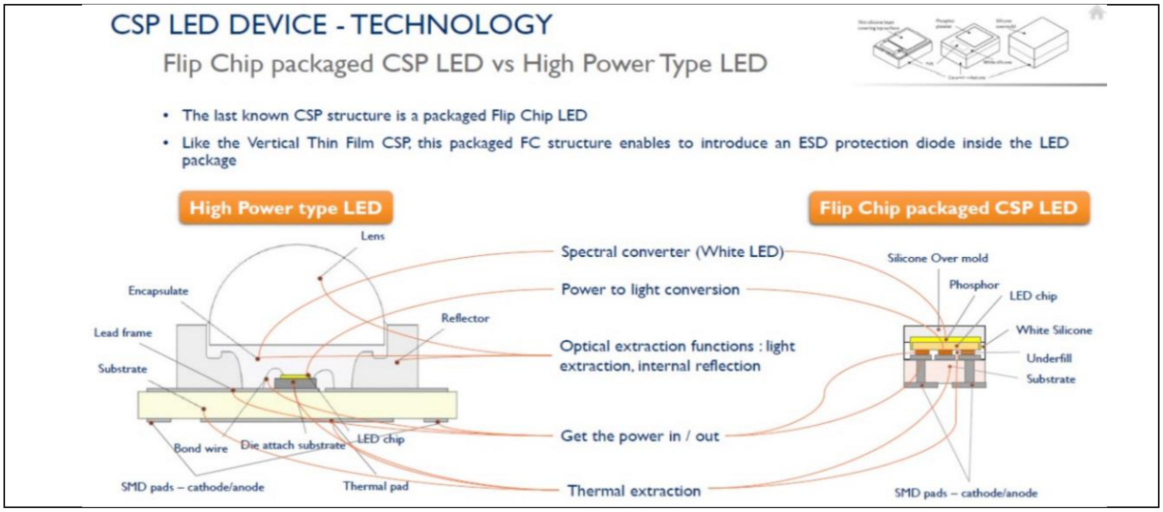


Fig.16 Flip Chip LED Characteristics



CSP LED DEVICE - TECHNOLOGY

Flip Chip packaged CSP LED vs High Power Type LED

- The last known CSP structure is a packaged Flip Chip LED
- Like the Vertical Thin Film CSP, this packaged FC structure enables to introduce an ESD protection diode inside the LED package

Fig.17 Structure of CSP Package with Flip Chip LED Inside. (ref: yole)

Applications of Various LED packages are necessitated by the structure of the luminaires & lamp shown in fig 18

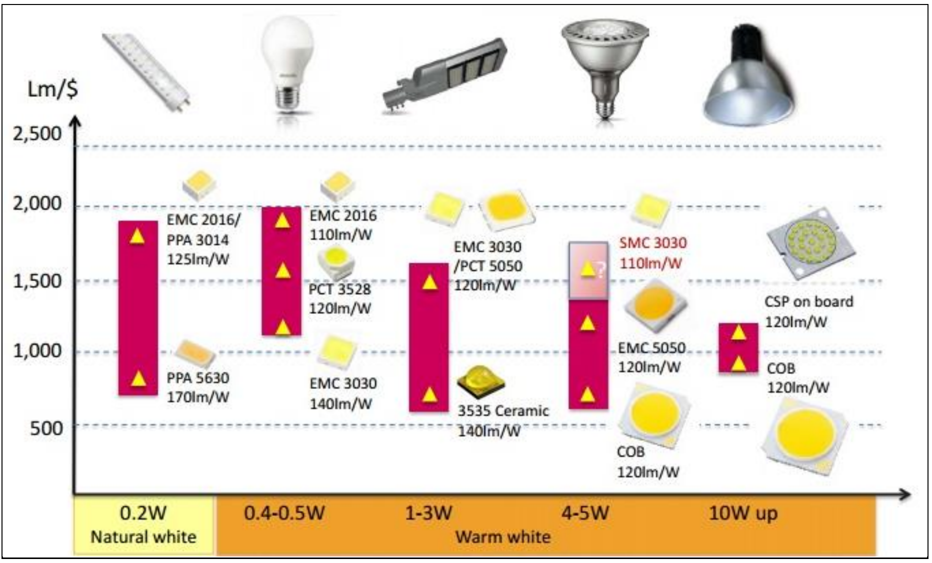


Fig.18 The Packages Types Are Related To The LED lamp & Luminaire Configuration.

9 LED ARRAY, LED MODULE & LED LAMPS & LUMINAIRE

An LED Array is a collection of LED packages on a printed circuit board or substrate, which may include optical elements and additional thermal, mechanical, and electrical interfaces. An LED module comprises of one or multiple LEDs that are connected to the load side of an LED driver, along with optional electrical, electronic, optical, and mechanical components.

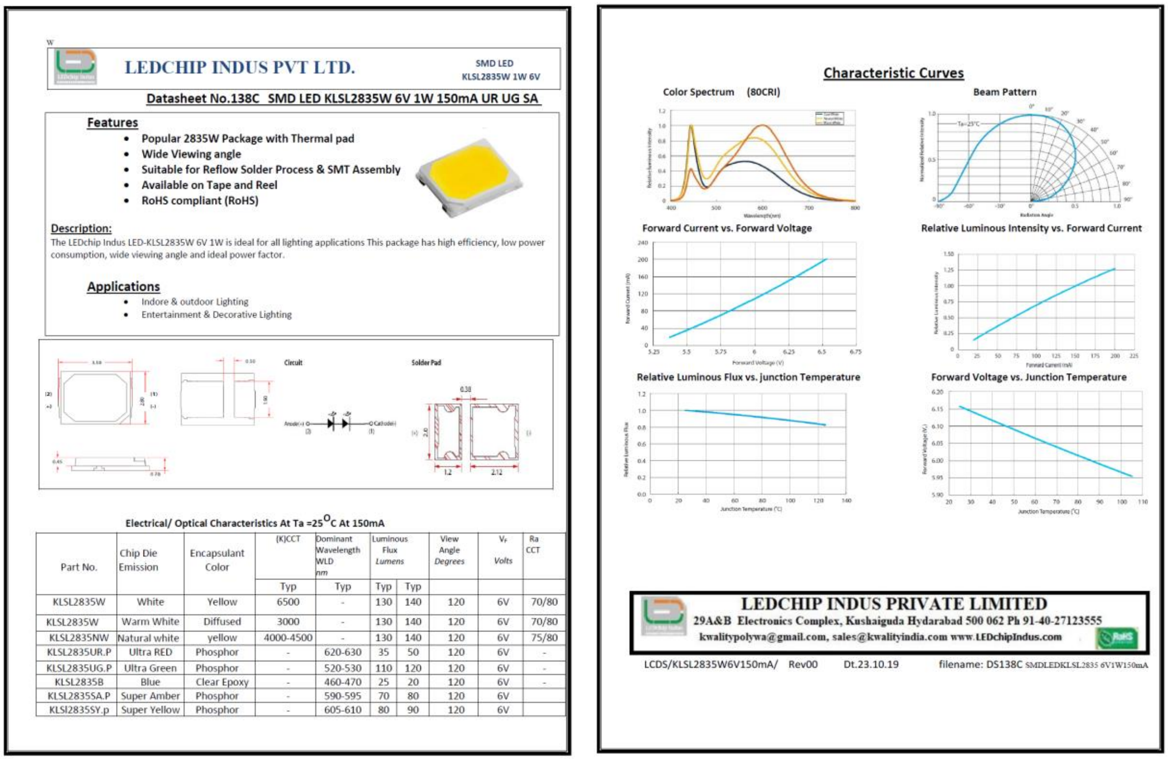
An LED lamp & Luminaire is a self-contained lighting unit that includes a light source, driver, components for light distribution and protection, and connection to a branch circuit. For detail of luminaires and LED lamps refer chapter LED lamps Part 3 section 2 & 3 respectively.

Effective utilization of LEDs necessitates efficient thermal coupling among the LED package, luminaire, and design application.

10 USING LED DATASHEETS FOR SELECTION OF FLUX, CCT COLOUR, CRI

A universal nomenclature for defining all characteristics of an LED does not exist. A multipage datasheet effectively conveys the pertinent characteristics. The provided data pertains to physical dimensions, as well as the highest values for DC current, peak forward current, LED junction temperature, reverse voltage limit, and operating and storage temperature ranges. The electrical and optical specifications for forward voltages (Vf), luminous flux/intensity, dominant wavelength or correlated colour temperature (CCT) x,y range, and view angle are provided for a given test current, including minimum, typical, and maximum values. The data sheet may include graphs depicting the relationship between wavelength shift and forward current, relative output and forward current, spectral power distributions, and a polar plot of luminous intensity. Operational data is temperature-sensitive and usually referenced to a 25°C ambient temperature in data guides.

This illustration displays a standard datasheet for the widely used SMD 2835 series of LEDs, which have a power capacity of 0.2W and are available in various colour emissions.



W

LEDCHIP INDUS PVT LTD.

SMD LED
KLSL2835W 1W 6V

Datasheet No.138C SMD LED KLSL2835W 6V 1W 150mA UR UG SA

Features

- Popular 2835W Package with Thermal pad
- Wide Viewing angle
- Suitable for Reflow Solder Process & SMT Assembly
- Available on Tape and Reel
- RoHS compliant (RoHS)

Description:

The LEDchip Indus LED-KLSL2835W 6V 1W is ideal for all lighting applications This package has high efficiency, low power consumption, wide viewing angle and ideal power factor.

Applications

- Indore & outdoor Lighting
- Entertainment & Decorative Lighting

Electrical/ Optical Characteristics At Ta =25°C At 150mA

Part No.	Chip Die Emission	Encapsulant Color	(K)CCT	Dominant Wavelength WLD *nm*	Luminous Flux *Lumens*		View Angle *Degrees*	V_F *Volts*	Ra CCT
			Typ	Typ	Typ	Typ			
KLSL2835W	White	Yellow	6500	-	130	140	120	6V	70/80
KLSL2835W	Warm White	Diffused	3000	-	130	140	120	6V	70/80
KLSL2835NW	Natural white	yellow	4000-4500	-	130	140	120	6V	75/80
KLSL2835UR.P	Ultra RED	Phosphor	-	620-630	35	50	120	6V	-
KLSL2835UG.P	Ultra Green	Phosphor	-	520-530	110	120	120	6V	-
KLSL2835B	Blue	Clear Epoxy	-	460-470	25	20	120	6V	-
KLSL2835SA.P	Super Amber	Phosphor	-	590-595	70	80	120	6V	
KLSl2835SY.p	Super Yellow	Phosphor	-	605-610	80	90	120	6V	

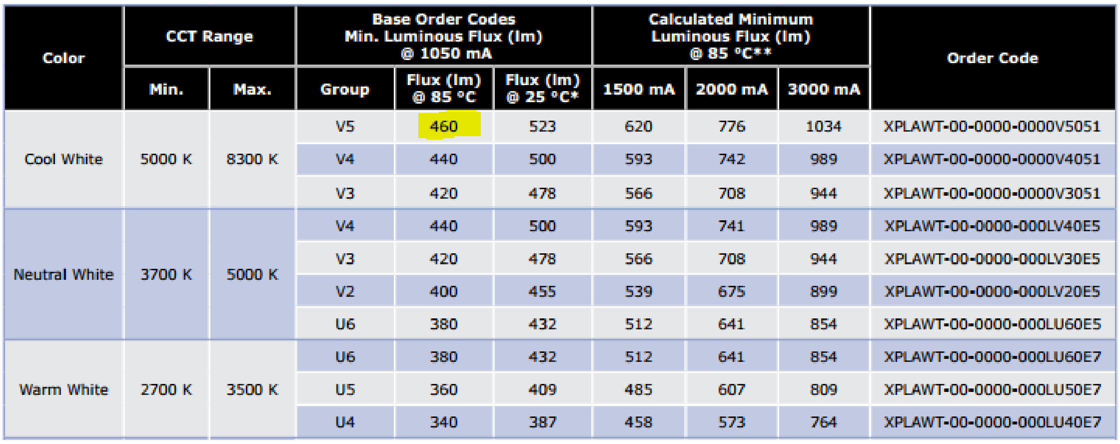
Characteristic Curves

LEDCHIP INDUS PRIVATE LIMITED
29A&B Electronics Complex, Kushaiguda Hydarabad 500 062 Ph 91-40-27123555
kwalitypolywa@gmail.com, sales@kwalityindia.com www.LEDchipIndus.com

LCDS/KLSL2835W6V150mA/ Rev00 Dt.23.10.19 filename: DS138C SMDLEDKLSL2835 6V1W150mA

Fig.19 Typical Data Sheet Of a Chip Company (Courtesy LED Chip Industry -Mr. Gupta)

The challenge is to choose an appropriate LED and driver combination that can produce the desired level of illumination. The LED temperature often rises rapidly in various applications, resulting in a decrease in lumen output. Datasheets for high power LEDs provide information on hot lumens at 85°C, as shown in the following example Fig 20.



Color	CCT Range		Base Order Codes Min. Luminous Flux (lm) @ 1050 mA			Calculated Minimum Luminous Flux (lm) @ 85 °C**			Order Code
	Min.	Max.	Group	Flux (lm) @ 85 °C	Flux (lm) @ 25 °C*	1500 mA	2000 mA	3000 mA	
Cool White	5000 K	8300 K	V5	460	523	620	776	1034	XPLAWT-00-0000-0000V5051
			V4	440	500	593	742	989	XPLAWT-00-0000-0000V4051
			V3	420	478	566	708	944	XPLAWT-00-0000-0000V3051
Neutral White	3700 K	5000 K	V4	440	500	593	741	989	XPLAWT-00-0000-000LV40E5
			V3	420	478	566	708	944	XPLAWT-00-0000-000LV30E5
			V2	400	455	539	675	899	XPLAWT-00-0000-000LV20E5
			U6	380	432	512	641	854	XPLAWT-00-0000-000LU60E5
Warm White	2700 K	3500 K	U6	380	432	512	641	854	XPLAWT-00-0000-000LU60E7
			U5	360	409	485	607	809	XPLAWT-00-0000-000LU50E7
			U4	340	387	458	573	764	XPLAWT-00-0000-000LU40E7

Fig.20 LED Luminous Flux Chart XP-L (Courtesy Cree LED)

If one needs to know the light output of a brightest available LED at a design current of say 2100mA, we start with selection a LED from the brightest bin V5. The 460 lumens (see the highlighted number) is the typical flux at 1050mA (the manufacturer's test current).

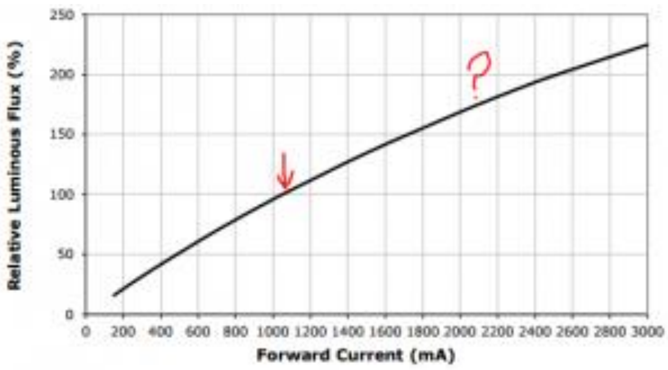


Fig.21 Relative Flux Versus Forward Current

Suppose we wish to power this LED using a 2100mA constant current LED driver. To determine the Flux output for this current, we use the relative flux vs. current' graph shown in Fig. 21 on the data sheet. The arrow is the tested (base) output (at 100% relative flux) ref Fig. 21.

Following the curve to 2100mA we see that this is a 75% increase in light. Taking the 460 lumens from ratings table and multiplying it by 1.75 we can see that the same LED running at 2100mA gives off about 805 Lumens.

In operation, LEDs will have a given voltage drop across them as shown in fig 22 which is dependent upon the material used. The voltage will also be partly dependent upon the level of current, so the current will be stated for this.

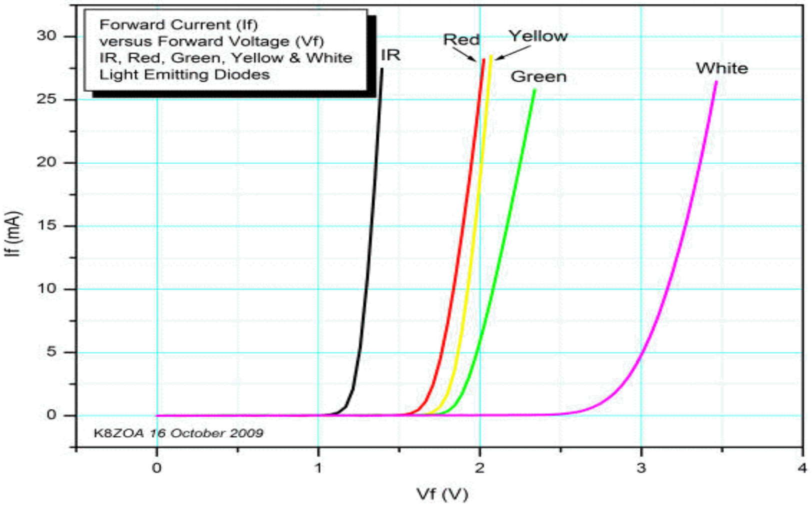


Fig. 22 LED Datasheets- Current vs Voltage - I/V Plot

11 PHOTOMETRY IN LEDS

The LED is an electro-optical component that requires characterization based on optical parameters. Radiometric units are utilized to measure optical quantities, using a detector that has a flat response. The determination of Luminous value is achieved through employment of a 'eye' detector that corresponds to the spectral response of the human eye.
Elementry of phometry and radiometry is explained in fig 23.

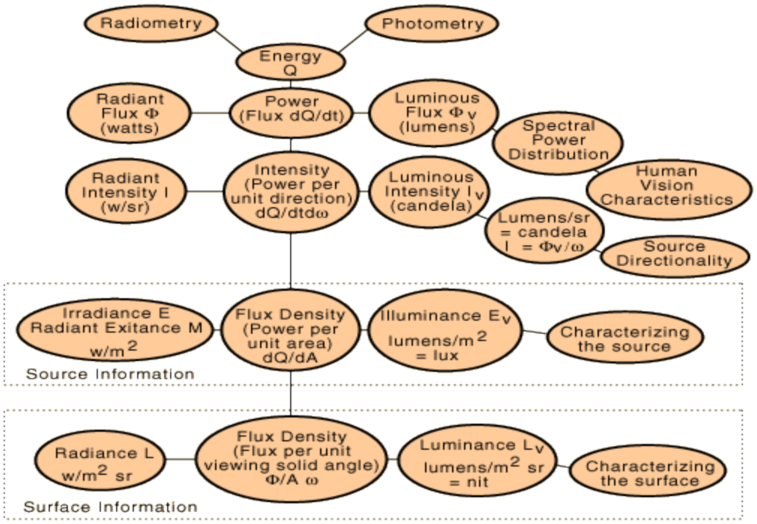


Fig. 23 Elements of Photometry & Radiometry

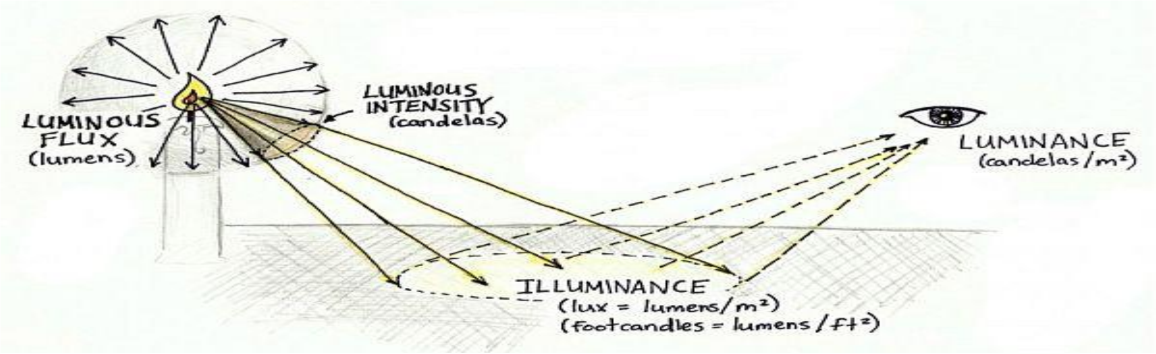


Fig. 24 Major Parameters in Photometry

The visual range the eye as detector the photometry is described in Fig. 23.

The LEDs are tested for electro optic characteristics at the rated current for various parameters. For the wavelengths beyond the visual range, the radiometric values are measured.

12 OPTICAL OUTPUT IN FLUX OR INTENSITY

Luminous Flux Φ_v is the total optical power coming out of a Light Source. Its measured in lumens with the help of calibrated Integrating Sphere. All wide-angle illuminating LEDs such as SMD white LEDs are measured for flux (Lumens) as shown in the Fig. 24.

Luminous Intensity I_v is the luminous flux emitted per solid angle. A candela is defined as one lumen per steradian. All unidirectional or narrow beam LEDs such as 5mm DIP LEDs are measured in candela or milli candela as shown in Fig. 24.

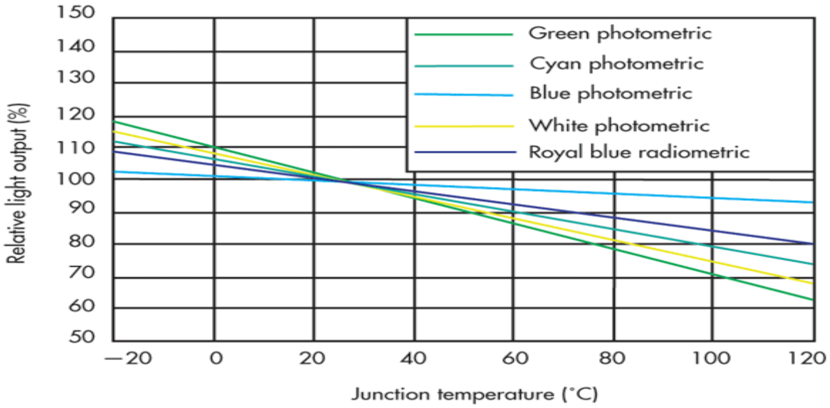


Fig. 25 Temperature vs Light Output. As Temperature Increases The Output Reduces.

As the lumen output at 85^{O} C could go down significantly, the luminaires are designed with the data at 85^{O}C, that is with ‘hot lumens’, to be in line with reality. At 25°C is the optimum design value. All are explained in Fig. 25.

13 CCT OR X, Y COORDINATES OR WLD

The correlated color temperature (CCT) of a given color is the temperature at which a black body emits the same color. Fig. 26, shows the CCT as seen different session w.r.t sun or candle light.

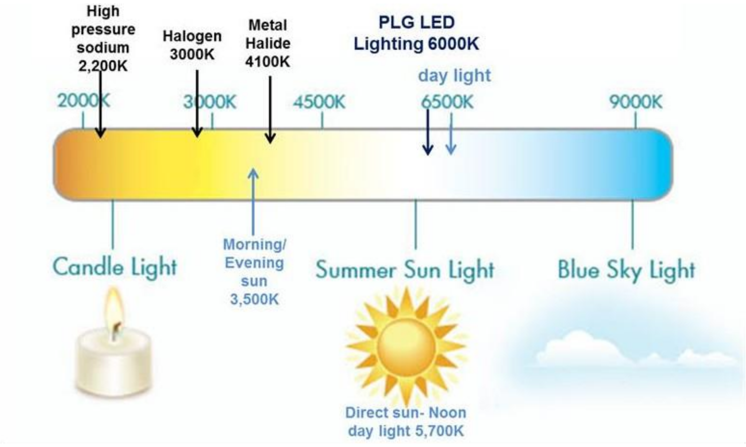


Fig. 26 CCT of Natural & Legacy Light Sources

For the white and mixed colors the LEDs are measured for x. y coordinates of CIE1937 curve. Corresponding CCT line on which this x, y point lies, is a more convenient parameter to comprehend the color and hence preferred parameter of color measurement.

The monochromatic LEDs or single color LEDs are measured for peak wavelength λ_p or WLP Φ_v, and half-width of the Band $\Delta\lambda$. However, the Human Eye has a response that varies with each wavelength of the light, there by tends to perceive the peak value shifted towards the greens. The perceived peak is called Dominant Wavelength λ_d or WLD.

14 LED EFFICACY

The LEDs have come a long way in efficiency up from 30 LPW ten years ago to 140-180 lumens per watt (LPW) in 2020. A laboratory green LED at 555 nm has produced 683 lumens per watt, the absolute maximum for human eye as shown in Fig. 27. Since white light is obtained by adding blue and red, to which eye response is poor, we end up with theoretical maximum of about 250 lumens per watt in White LEDs. Details of CCT vs lumen per watt (efficacy) plot for various light sources and LED light sources.

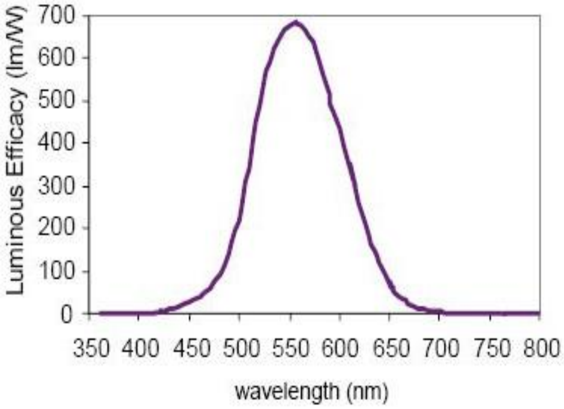


Fig. 27 Luminous Efficacy Versus Wavelength

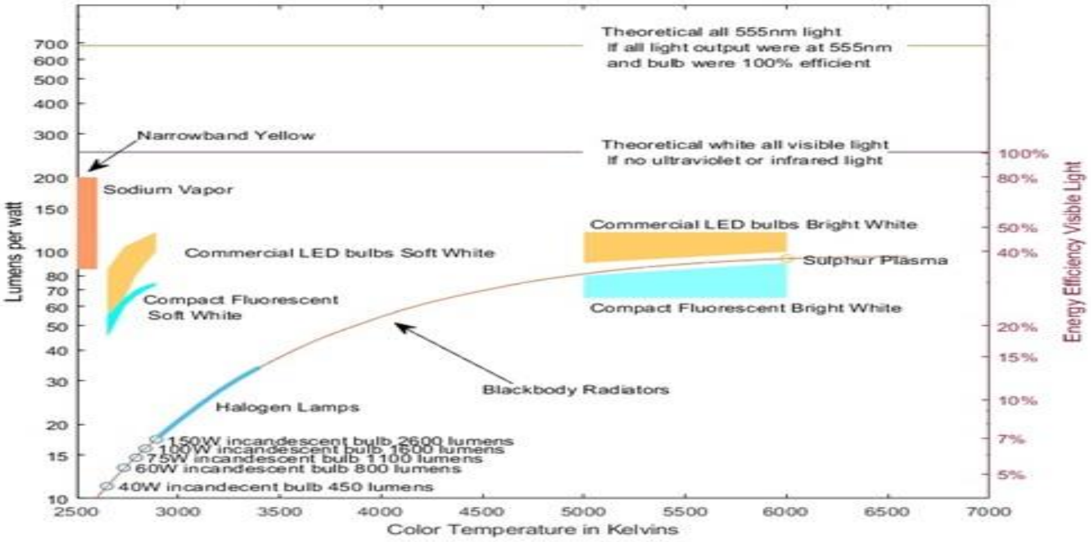


Fig.28 Plot for lm/W versus Colour Temperature

15 COLOR UNIFORMITY AND BINNING

Uniformity problems are a result of the inherent complexities of manufacturing semiconductors as different parts of the wafer are bound to have differing properties as also from batch-to-batch. Human eye, though having less sensitive logarithmic response to brightness, detects smallest difference in color space, measured in McAdam Steps, which result from unavoidable variance in phosphor volume or density.

Hence a process called Binning is employed where automatic machines test and LEDs are placed into similar categories, or bins, with the category/bin defined by the similarity in lumens, colour and voltage. Lumens and colour are the most important parameters in LED variability. This results in batches of LEDs that have only the slightest deviations in performance from one another. Fig 29 explains details of area of the colour deviation I colour temperature vs x-y coordinates or colour space.

LEDs bin limits can be as per own criteria or according to ANSI C78.377. A 3-Step Bin will offer more uniform LEDs than say a 7 step binning.

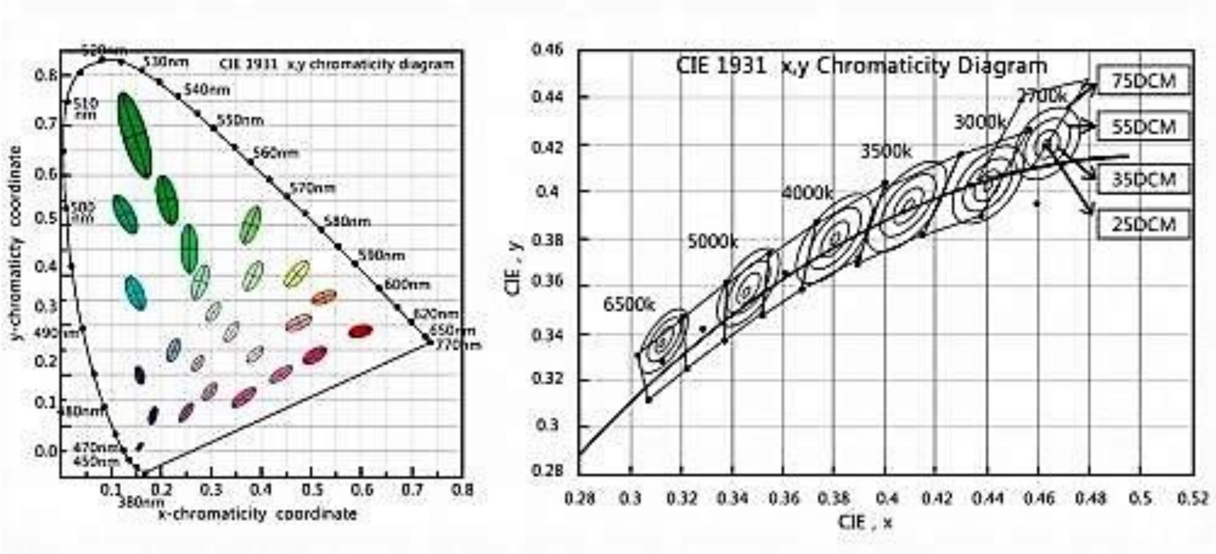


Fig. 29 The Plot Depicting Width Of SDCM Or Mcadam Step Varies By Location In Color Space

16 STANDARD DEVIATION COLOUR MATCHING (SDCM)

SDCM is an acronym which stands for Standard Deviation Colour Matching as shown in Fig. 30. SDCM has the same meaning as a “MacAdam ellipse”. A 1-step MacAdam ellipse defines a zone in the CIE 1931 2 deg (xy) colour space within which the human eye cannot discern colour difference. the size of an SDCM ellipse is quite small, which means that the human vision system is very good at discriminating colour differences when viewing two light sources at the same time. Most LEDs are binned at the 4-7 step level, in other words you certainly can see colour differences in LEDs that are ostensibly the same colour.

American standard ANSI C78.377-2008 “Specification for the Chromaticity of Solid State Lighting Products” places white LEDs into standard color groups which all have the same “nominal” CCTs, calLED standard deviation colour matching. SDCM is just noticeable colour difference (JND) where 50% of observers see a difference and 50% of observers do not see a difference. SDCM are found to be elliptical. The size of the ANSI C78.377 nominal CCT quadrangle is a 7-step McAdam ellipse or 7 step SDCM.

So if LEDs binned to a 3-step MacAdam ellipse tolerance (or 4xSDCM), they are better than LEDs that are binned to 5-steps but you will still see a colour difference over the range of LEDs supplied to that specification as example in Fig 30.

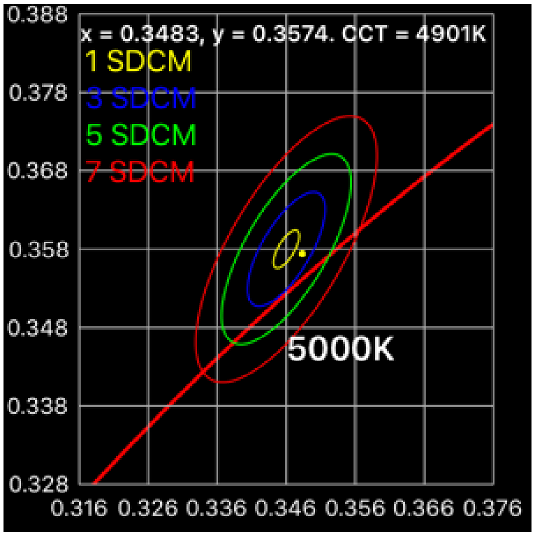


Fig. 30 Plot Showing the SDCM for LEDs

17 COLOR STABILITY

Some LEDs shift in color with changes in the junction temperature, which may be a result of dimming. It is not possible to generalize the magnitude of the color shift. AlInGaP LEDs (above about 580 nm) tend to have larger colour shifts with a change in temperature than to InGaN LEDs (below about 550 nm). LED lamps may also shift in color as they age, and different spectral components may have unequal lumen depreciation. Some multimodal LED systems that create white light with the additive mixing of red-, green-, and blue-emitting LEDs employ active feedback to hold chromaticity constant during dimming and over life. This is achieved by differentially adjusting the red-, green-, and blue-emitting components. LED lamps that employ a phosphor tend to be less susceptible to color shift with respect to both diming and life.

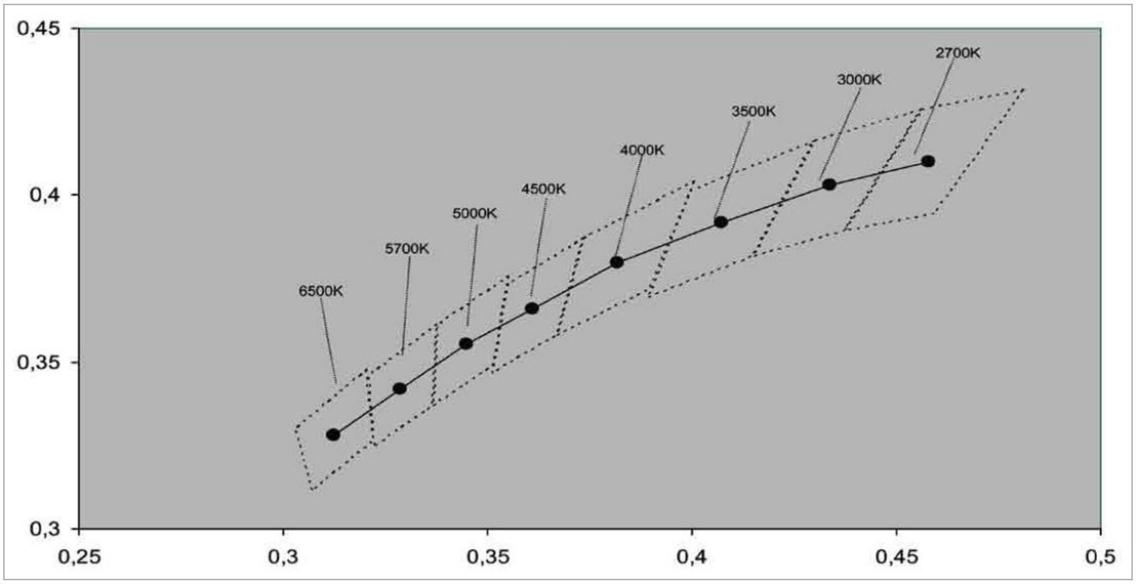


Fig. 311 Graphical Representation of the Chromaticity Specification Of Nominally White SSL Production

Table 5 Chromaticity of various White CCTs wrt to ANSI C378.377 has been clearly sated the tolerance

Table 5 Tolerance of CCT as Per ANSI

	2,700 K		3,000 K		3,500 K		4,000 K		4, 500 K		5,000 K		5,700 K		6,500 K	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Center point	0.4578	0.4101	0.4338	0.4030	0.4073	0.3917	0.3818	0.3797	0.3611	0.3658	0.3447	0.3553	0.3287	0.3417	0.3123	0.3282
Tolerance Quadrangle	0.4313	0.4319	0.4562	0.4260	0.4299	0.4165	0.4006	0.4044	0.3736	0.3874	0.3551	0.3760	0.3376	0.3616	0.3205	0.3481
	0.4562	0.4260	0.4299	0.4165	0.3996	0.4016	0.3736	0.3874	0.3548	0.3736	0.3376	0.3616	0.3207	0.3462	0.3028	0.3304
	0.4373	0.3893	0.4147	0.3514	0.3889	0.3690	0.3670	0.3578	0.3512	0.3465	0.3366	0.3369	0.3222	0.3243	0.3063	0.3113
	0.4593	0.3944	0.4373	0.3893	0.4147	0.3814	0.3898	0.3716	0.3670	0.3578	0.3515	0.3487	0.3366	0.3369	0.3221	0.3261

18 D_{uv}

A **D_{uv}** value provides information on the distance and direction of a color shift from the Planckian locus on the CIE 1960 u-v coordinates. When **Duv** value is closer to zero, the light source is more like an ideal one.

Table 6 shows the Nominal CCT & Duv values defined by C78.377which is also followed in our BIS standard for testing CCT allowances of a lighting system.

Table 6 CCT Tolerance Value as Per CIE

Sl. No (1)	Nominal CCT (2)	Target CCT and tolerance (K) (3)	Target D_{uv} and tolerance (4)
1	2700K	2725 ± 145	0.000 ± 0.006
2	3000 K	3045 ± 175	0.000 ± 0.006
3	3500 K	3465 ± 245	0.000 ± 0.006
4	4000 K	3985 ± 275	0.001 ± 0.006
5	4500 K	4503 ± 243	0.001 ± 0.006
6	5000 K	5028 ± 233	0.002 ± 0.006
7	5700 K	5665 ± 355	0.002 ± 0.006
8	6500 K	6530 ± 510	0.003 ± 0.006
9	Flexible CCT (2700-6500 K)	T ±ΔT	D_{uv} ± 0.006

19 CRI of LED

Colour rendering index (CRI) is a measure of how similar object colors appear under illumination by a test source compared to the object colours under mid day sun represented by a reference illuminant, typically expressed as a CRI.

Ra = average of R1 to R8 & Re = average of R1 to R15. R9 the saturated red is difficult to achieve and needs right phosphor mix.

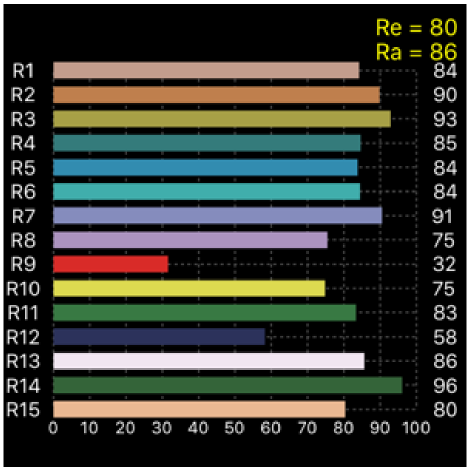
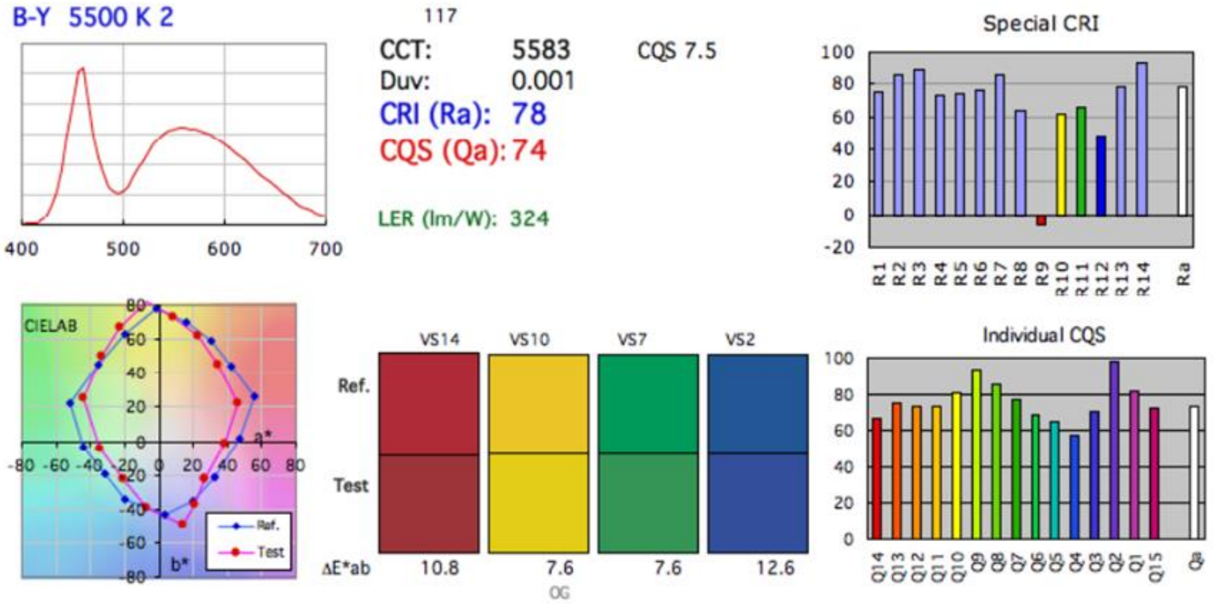


Fig. 32 CRI Histogram with R1 to R15 Values



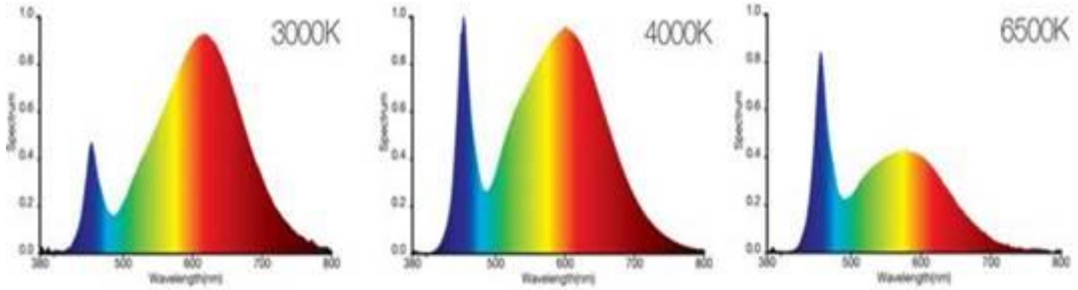


Fig. 33 LED Spectra for 3000K 95Ra vs 4000K 94Ra vs 6500K 70Ra

20 COLOR FIDELITY

Light detectors in the EYE are rods & cones. The cones are three types, each responds a portion of the spectrum, with peaks of blue, green, and red light. The interaction of these groups is then responsible for the stimulus which is interpreted by the brain as color. This theory on color vision is TRICHROMATIC THEORY.

LED light sources achieve a wide range of color qualities, depending on the requirements of the lighting application. High levels of color quality generally measured by CRI, there are typically cost and efficiency trade-offs most of the times.

Fig.34 Colours used to calculate CRI Ra

A CRI of 80 recommended for interior lighting. CRI of 90 or higher indicates excellent color fidelity; LEDs can also meet this threshold.
CRI is far from a perfect metric and is especially poor at predicting the fidelity of saturated reds, for which the supplemental value R_9 is often used. Color rendition perceptions can vary with chromaticity, with an interactive effect of CCT and Duv. New metrics, such as the fidelity index (R_f) and the gamut index (R_g), which are described in IES TM-30-15, can provide a more comprehensive evaluation of color rendering.

Instead of a single fidelity value, as with CRI Ra, TM-30-15 IES Method for Evaluating Light Source Color Rendition gives us a wealth of data about the color rendering of the light source in question. The first is the Fidelity Index Rf. Like Ra, it is a comparison of the color rendering of the test light source compared to the reference light source. However, with 99 color samples it is a tougher test that cannot be gamed.
The second is the Gamut Index Rg. Rg indicates the average change in saturation of the 99 color samples as rendered by the test source compared to the reference source.

A gamut index of 100 means that, on average, the test light source doesn't change the hue or saturation of the CES compared to the reference source. An Rg above 100 indicates that the test light source, on average, increases the saturation of the CES producing colors that are more vivid. An Rg below 100 indicates that the test light source decreases the saturation of the CES producing colors that are less saturated.

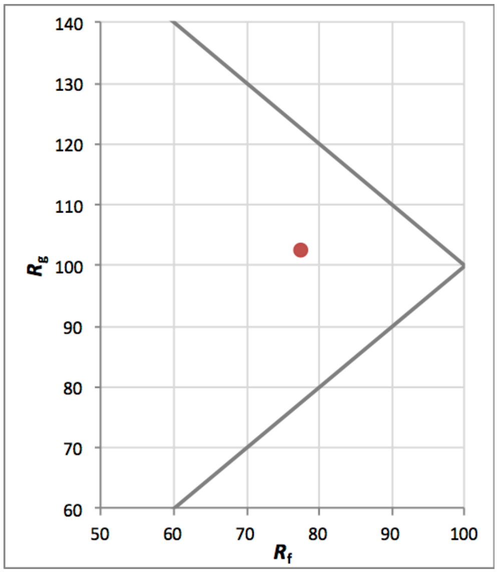


Fig. 35 Relation of Rg vs Rf

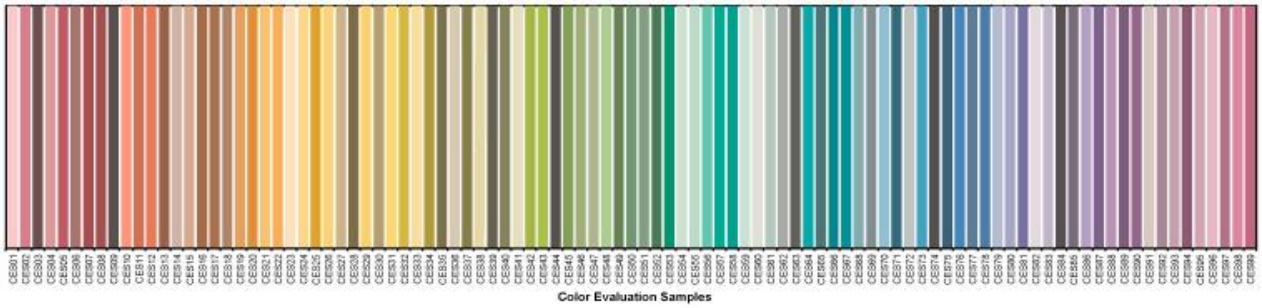


Fig. 36 Colours Used In The TM-30 Chosen Across CAM02-UCS The Most Modern Colour Space.

The Color Distortion Icon, is plotted on the CAM02-UCS color space. In this graphic Fig. 36 both the reference source and the test source are shown, along with an indication of the direction and magnitude of the hue shift caused by the test source. Finally, we can even look at the color shift for each of the 99 CES.

A designer using TM-30 now has three big picture metrics to evaluate a light source: color fidelity (Rf), color gamut (Rg), and correlated color temperature (CCT). The designer can use TM-30's calculation tool to examine the Rf and Rg of a light souce in as much detail as the project merits, from a very broad overview to a very detailed, color by color, evaluation.

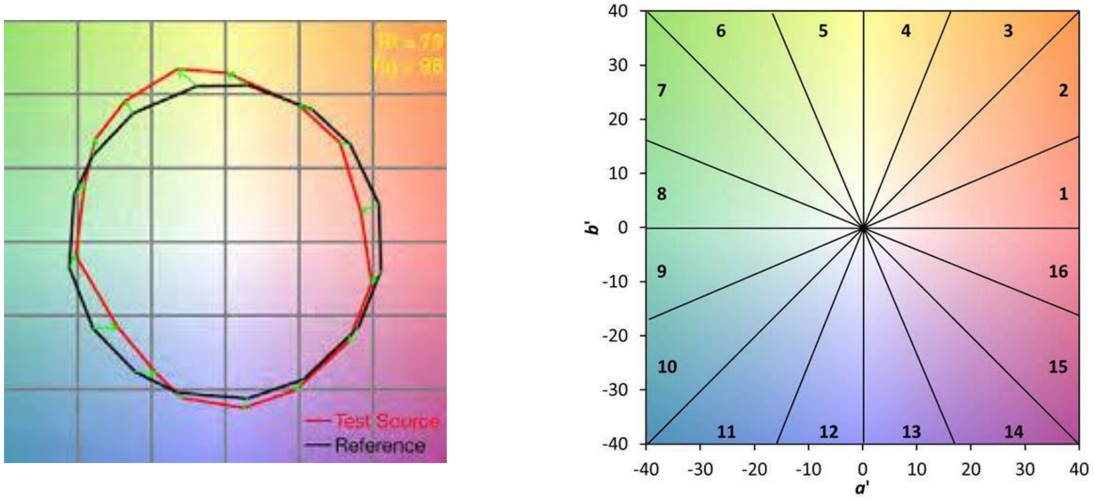


Fig. 37 TM-30 16 Sectors & Colour circle

21 COLORIMETRIC CALCULATIONS

-The chromaticity (x,y)CIE 1931 and / or (u',v',) CIE 1976 and correlated color temperature (CCT, unit: Kelvin) are calculated from the relative spectral distribution of the SSL product.

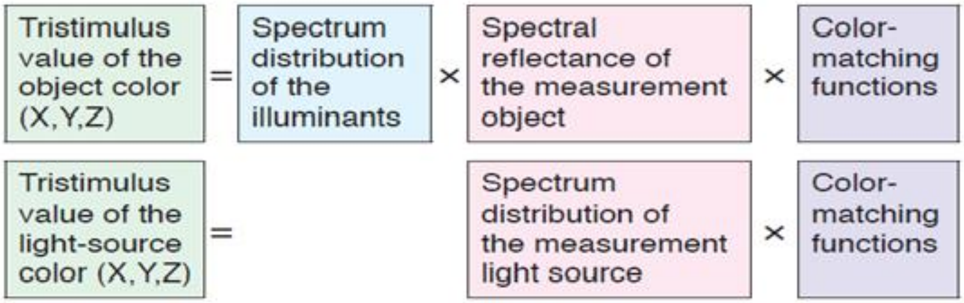


Fig. 38 Calculation of x,y,z in CIE 1931

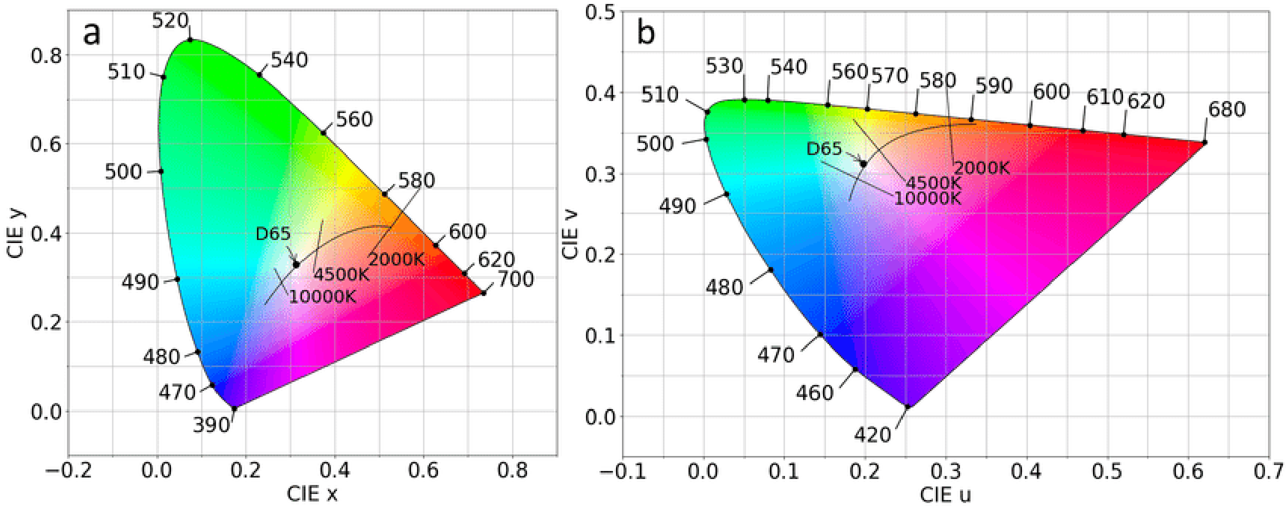


Fig. 39 The CIE 1931 (X,Y) & CIE 1976 UCS Color(U′, V′) Space Chromaticity Diagram. The Outer Curved Boundary Is The Spectral (Or Monochromatic) Locus.

22 CHROMATICITY AND DOMINANT WAVELENGTH FOR LEDS

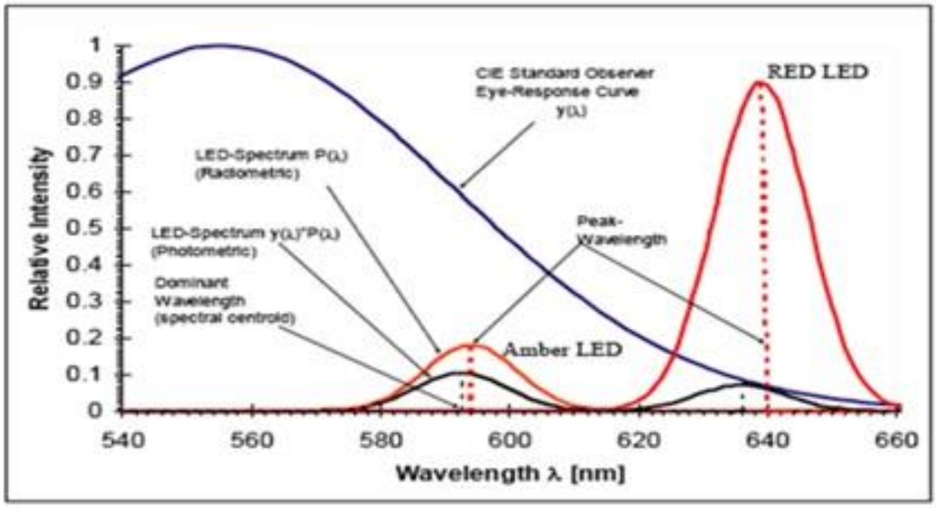


Fig. 40 Dominant Wavelength WLD Is The Peak As Perceived By The Skewed Eye Sensitivity.

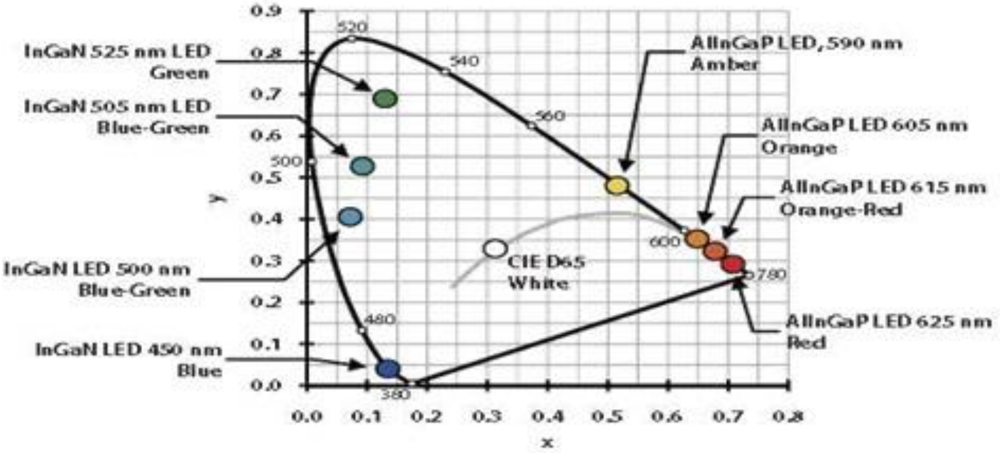


Fig. 41 Dominant Wavelength of Various Compounds

23 SPECTRAL POWER DISTRIBUTION

In radiometry, photometry, and colour science, a spectral power distribution (SPD) measurement provides information about the power per unit area per unit wavelength of an illumination source or radiant exitance. It describes the distribution of radiant energy across the electromagnetic spectrum.

SPDs are commonly used to characterize the colour properties of light sources. They can be measured and represented graphically, showing the intensity or power at each wavelength. By examining the shape and distribution of the SPD, we can understand the spectral composition of light emitted by a particular source.

Chromaticity is another important concept related to SPDs. It refers to the quality of colour of a light source and is determined by its relative proportions of different wavelengths. Chromaticity coordinates, such as x and y or u' and v', are often used to represent the color properties of a light source on a chromaticity diagram, such as the CIE 1931 xy or CIE 1976 uv chromaticity diagram.

The dominant wavelength of a light source represents the wavelength at which its spectral power distribution peaks or has the highest intensity. It is a measure of the perceived color of the light source. For monochromatic light sources, such as lasers, the dominant wavelength corresponds to the single wavelength emitted.

When comparing different light sources, their SPDs can be evaluated based on how close they plot to the spectrum locus on a chromaticity diagram. The spectrum locus represents the range of colours visible to the human eye and corresponds to monochromatic light at various wavelengths. Light sources that plot closer to the spectrum locus generally have a narrower spectral power distribution and may exhibit more saturated or pure colours.

SPDs are often displayed with normalized values for convenience, where the values are scaLED to a maximum of 1. This normalization allows for easier comparison and analysis of different SPDs.

Overall, spectral power distribution measurements provide valuable insights into the color properties and composition of light emitted by various sources, enabling a deeper understanding of light and its interaction with objects and the human visual system.

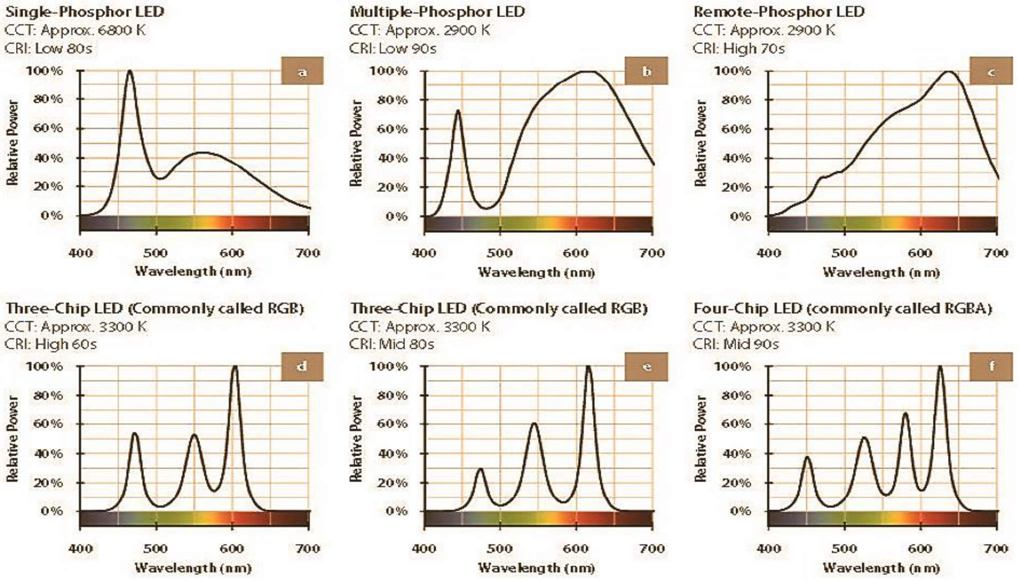


Fig.42 SPD of LEDs

24 COLOR TUNING OF A LED LIGHT SOURCE

The use of three separately controllable RGB LEDs per pixel is a common method to achieve color changing effects, as seen in TV or phone displays. By varying the current in each of the red, green, and blue LEDs, different combinations of colors can be produced, allowing for a wide range of hues and shades.

In the field of LED lighting, there are applications that involve changing the light to suit different moods and fulfill circadian lighting needs. One approach is to use a mix of cool white and warm white LEDs in a random cluster. By adjusting the ratio of current driven through each colour string, the overall emission colour can be tuned. This allows for the creation of lighting scenarios that promote wakefulness or induce sleep, aligning with the body's natural circadian rhythm.

Another area where LED lighting is extensively used is horticulture lighting. Different stages of plant growth, such as rooting, flowering, and overall growth, have specific light requirements. LED systems designed for horticultural purposes often incorporate blue, yellow, and red LEDs that can be switched on or off to provide the appropriate light spectrum for each stage. This targeted control of light wavelengths helps optimize plant growth and productivity.

LED technology offers great flexibility in achieving precise and dynamic colour control, allowing for customized lighting solutions in various applications, including entertainment displays, mood lighting, circadian lighting, and horticulture.

25 LED LIFE & THERMAL CHARACTERISTICS

Heat has a significant impact on various characteristics of LEDs, including lumen output, luminous efficacy, emission color, and overall lifespan. The performance of LEDs is directly influenced by the temperature of the p-n junction.

LED package designs have been continuously optimized to improve heat dissipation and enable faster evacuation of heat from the junction. Efficient thermal management is essential to maintain lower junction temperatures, which helps to preserve the performance and longevity of the LED.

While LEDs are highly efficient in converting electrical energy into light energy, it is true that a significant portion of the electrical power is still dissipated as heat. Ongoing research and development in LED technology aim to enhance the efficiency of these devices by improving the crystal structure and optimizing various aspects of the LED design.

Efforts are being made to develop more perfect crystals that promote better radiative recombination of electron-hole pairs, reducing the re-absorption of photons within the crystal. Strategies such as index-matching encapsulants and changes in geometry and surface etching are employed to extract more light at the crystal-air interface and minimize total internal reflection of slant rays. Reflecting substrates can be utilized to enhance light extraction, while measures are taken to inhibit defect propagation and improve current spreading within the LED structure. Minimizing the Auger effect, which causes a reduction in efficiency at high current densities, is also an active area of research.

By addressing these factors and continuously refining LED designs, researchers and manufacturers strive to improve the overall efficiency and performance of LEDs, reduce thermal losses, and enhance the reliability and lifespan of LED lighting systems.
Heat density is an important aspect to consider when it comes to light-emitting diodes (LEDs). LEDs are semiconductor devices that convert electrical energy into light. However, during the process of converting electricity to light, they also generate heat.

Heat density refers to the amount of heat generated per unit area within an LED. It is influenced by various factors, including the efficiency of the LED, the amount of current passing through it, and the design of the LED package.

LEDs have higher heat densities compared to traditional incandescent or fluorescent lights. This is because LEDs are more efficient in converting electrical energy into light, resulting in less energy being wasted as heat. However, even with their high efficiency, a significant amount of heat is still generated.

Managing heat in LEDs is crucial because excessive heat can lead to performance degradation and reduce the lifespan of the device. It can also affect the color quality and stability of the emitted light. Therefore, LED manufacturers incorporate various heat management techniques to dissipate the generated heat efficiently.

Common heat management techniques include heat sinks, thermal interface materials, and proper ventilation or cooling systems. Heat sinks are designed to absorb and dissipate heat away from the LED junction, preventing overheating. Thermal interface materials, such as thermal pastes or pads, help improve heat transfer between the LED and the heat sink. Ventilation and cooling systems, such as fans or heat pipes, help maintain a suitable operating temperature for the LED.

Efficient heat management is essential in high-power LEDs used in applications such as lighting, automotive headlights, or electronic displays. By effectively dissipating heat, the LED's performance, reliability, and overall lifespan can be improved, ensuring optimal operation and longevity.

The temperature at the solder or T-point of a light-emitting diode (LED) can have a significant impact on its performance, reliability, and lifespan. The solder point temperature refers to the temperature at the point where the LED is soldered onto a circuit board or a heat sink.

Excessive solder point temperature can adversely affect LEDs in several ways:

26 EFFICIENCY AND LIGHT OUTPUT

Higher temperatures can decrease the efficiency of LEDs, leading to reduced light output. The conversion of electrical energy to light becomes less efficient as the temperature rises, resulting in lower overall luminous efficacy. This can affect the brightness and quality of the emitted light, impacting the LED's intended application.

26.1 Color Shift: LEDs are available in various colors and color temperatures. However, excessive heat can cause a color shift, altering the perceived color of the emitted light. This can be particularly problematic in applications where color accuracy is crucial, such as display screens, signage, or architectural lighting.

26.2 Degradation and Lifespan: Heat is a major contributor to LED degradation and can significantly impact its lifespan. Elevated temperatures accelerate the aging process of the LED, leading to a shorter operational life. The excessive heat can degrade the LED's semiconductor materials, reducing its reliability over time.

26.3 Thermal Stress: Rapid and extreme temperature changes, such as thermal cycling, can induce thermal stress in the LED. The difference in expansion and contraction rates between the LED materials and the surrounding components or solder can lead to mechanical stress and potentially result in cracking or delamination, compromising the LED's integrity.

To mitigate the impact of solder point temperature on LEDs, proper thermal management is crucial. This includes:

26.4 Heat Dissipation: Efficient heat dissipation is essential to maintain the solder point temperature within acceptable limits. Heat sinks, thermal pads, or thermal interface materials help conduct heat away from the LED and into the surrounding environment or a dedicated heat sink.

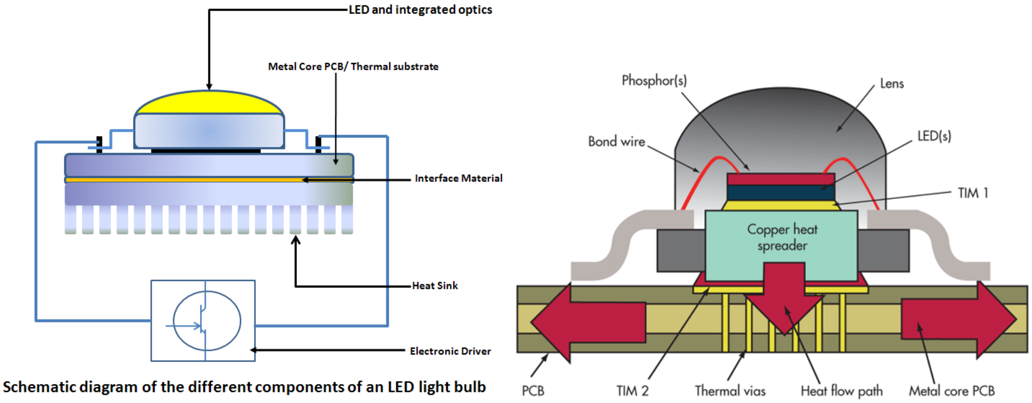
26.5 Adequate Design: Proper LED packaging and circuit board layout can facilitate heat transfer and minimize temperature rise. Designs that incorporate thermal vias, copper traces, or thermal pads can enhance heat dissipation and distribute the heat more evenly.

26.6 Thermal Monitoring: Temperature sensors or thermal monitoring systems can be employed to monitor the solder point temperature. This allows for real-time feedback and ensures that appropriate measures can be taken if the temperature exceeds safe limits.

By carefully managing the solder point temperature, LED manufacturers and designers can optimize the performance, reliability, and lifespan of LEDs, ensuring consistent light output, color stability, and longevity in various applications.

In contrast to filament bulbs, which emit all of their heat, LEDs absorb the excess heat, resulting in an increase in the junction temperature and a subsequent decrease in the photon generation efficiency of the LED. It is pertinent to acknowLEDge the significance of effectively dissipating this thermal energy. LED luminaires have the potential to increase their lifespan by up to ten times. Despite the significant amount of heat generated, it is possible to prevent an increase in LED junction temperature by continuously dissipating this heat to an infinite heatsink, such as the ambient atmosphere. This is precisely the design objective for the metal housing utilised in LED applications.

The thermal energy generated by the LED chip is dissipated through the lower metallic pad within the LED package, subsequently transferring to the copper layer of the printed circuit board (PCB), and ultimately to the aluminum casing of the Metal Core PCBs. Finally, the heat is released to the aluminum body of the lamp. The exterior of the body is designed with a multi-finned structure to enhance the surface area, thereby augmenting the heat dissipation through the process of convection. It is imperative to ensure that the luminaire is situated in a location that provides sufficient air ventilation.



Schematic diagram of the different components of an LED light bulb

Fig. 43 Importance of thermal interface materials (TIM) in LED bulbs & Luminaires

27 TIM- THERMAL INTERFACE MATERIAL

The importance of thermal management and the role of a thermal interface material (TIM) in ensuring effective heat transfer in LED applications.

The interface between the LED and the MCPCB (Metal Core Printed Circuit Board) or the MCPCB and the metal housing often contains tiny air voids, which act as thermal barriers and impede heat flow. To address this issue, it is crucial to use a thermally conductive paste or TIM to fill these voids and establish good thermal contact between the surfaces. Applying the TIM and using appropriate fasteners to tightly press the surfaces together helps eliminate air gaps and improves heat transfer.

Additionally, achieving a high level of surface planarity between the MCPCB and the housing is important to optimize heat dissipation. This ensures efficient thermal conduction from the LED to the heatsink and facilitates the transfer of heat to the surrounding environment.

When it comes to selecting a heatsink, the mass of the heatsink itself is less critical than maximizing the fin surface area for enhanced convection losses. Increasing the surface area allows for better heat dissipation into the ambient air. It is also essential to use a high conductivity TIM to facilitate the transfer of heat from the LED to the heatsink, enabling the LED to operate at lower temperatures.

It's worth noting that if plastic enclosures are placed over the heatsink body for aesthetic purposes, they can hinder heat evacuation and reduce the effectiveness of the heatsink. Proper consideration should be given to the design to ensure that heat can efficiently dissipate from the heatsink.

The importance of thermal management lies in maintaining a lower LED junction temperature. Even a small reduction in temperature, such as 10°C, can significantly extend the LED's working life by as much as 20,000 hours. Therefore, it is crucial to prioritize thermal design and strive to reduce every degree of heat to maximize the LED's lifespan.

The improvement in LED packages and their thermal design has played a significant role in reducing the thermal resistance (Rth) and enhancing overall thermal management.

LED packages have undergone advancements to improve their ability to dissipate heat efficiently. These improvements include optimizing the design of the package to minimize thermal resistance and enhance thermal conductivity. The development of new materials, such as high thermal conductivity substrates and encapsulants, has also contributed to better heat dissipation.

By reducing the thermal resistance from the LED chip to the terminal pads, the heat generated within the LED can be more effectively transferred to the surrounding environment. This helps in maintaining lower junction temperatures and improves the overall thermal performance of the LED.

The evolution of LED packages has seen the introduction of various designs, such as ceramic packages, metal-core packages, and flip-chip packages, each offering different thermal properties and performance characteristics. These advancements have allowed for better heat transfer, improved thermal stability, and increased reliability of LED products.

Optimizing thermal management not only enhances the LED's performance and efficiency but also extends its overall lifespan. By effectively dissipating heat and maintaining lower junction temperatures, the LED can operate under more favorable conditions, reducing the risk of thermal stress and degradation.

Therefore, it is essential to consider the thermal characteristics and design of LED packages when selecting LEDs for specific applications. The continuous improvement in LED package designs and thermal management techniques provides opportunities for achieving better performance, reliability, and longevity in LED lighting systems. Fig.44 given typical example of thermal resistance of LED packages & thermal profile for different LED packages shown in Fig.45.

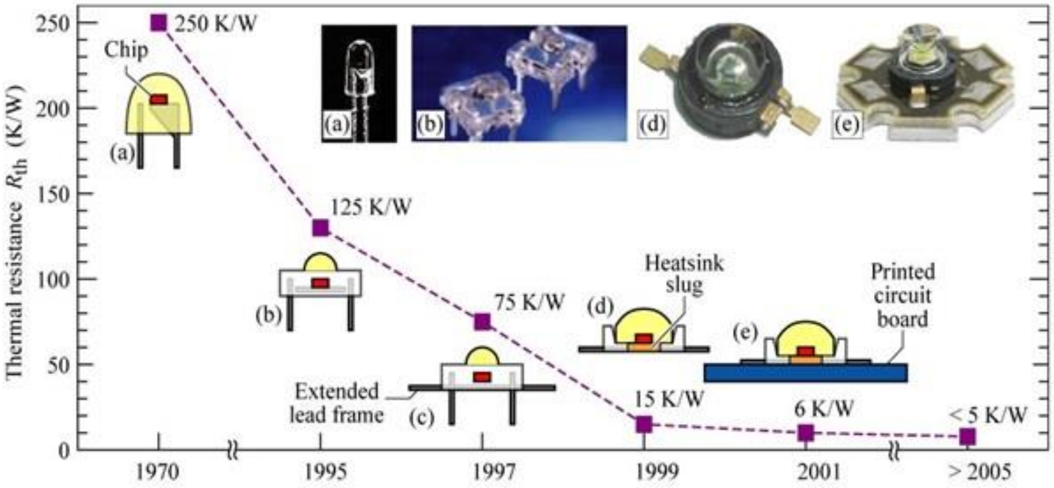
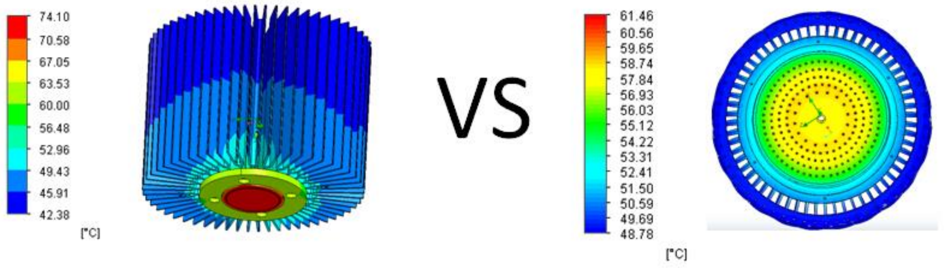


Fig. 44 Thermal Resistance Of LED Packages 5mm, Superflux, Superflux Extended, Emitter, Star Leds.



COB Chips, 74 degree

SMD Chips, 57 degree

Fig. 45 Temperature Profile Comparison Of COB And SMD LED Cluster..

28 LIFE AND LUMEN MAINTENANCE

The life of an SSL (Solid State Lighting) system, such as LEDs, is typically defined based on the degradation of lumen output over time. The most common measure used for LEDs is the L70 value, which represents the time it takes for the LED to reach 70% of its initial lumen output. This method assumes that LED lamps that fail catastrophically will be replaced.

For Organic LEDs (OLEDs), the commonly employed measure is L50, which represents the time it takes for the OLED to reach 50% of its initial lumen output. This lower percentage reflects the different characteristics and performance of OLED technology compared to traditional LEDs.

The choice between using L70 or L50 as the defining metric depends on the specific application and the desired level of light output. L70 is commonly used in general illumination applications where maintaining a high level of light output is important. This value indicates that the LED has experienced a 30% loss in lumen output, which may be considered as the end-of-life point.

On the other hand, L50 may be more appropriate for decorative applications where the precise quantity of lumens is not as critical. These applications may allow for a greater level of light output degradation before the LED is considered to have reached the end of its useful life.

Ultimately, the selection of L70 or L50 as the appropriate measure for a given application depends on factors such as the desired light level, aesthetics, and maintenance considerations. Manufacturers and designers should carefully consider these factors and consult the relevant standards and guidelines to determine the most suitable approach for defining LED lamp life in a specific application.

28.1 Expected LED lifetime

LED lighting systems generally experience a gradual reduction in light output over time rather than sudden catastrophic failures. This degradation in light output is an important factor to consider, especially in applications where maintaining a certain level of light is crucial.

The LED lifetime is commonly expressed using the (B50, L70) notation, which refers to the time it takes for either 50% of the LED population to fail catastrophically (B50) or for the LED to degrade by more than 30% from its initial lumen output (L70). The specific values for B50 and L70 can vary significantly depending on the type of LED package used.

For non-critical areas or applications where a slight decrease in light output is acceptable, the L50 figure may be used instead. This indicates the time at which the LED is estimated to produce 50% of its initial lumens.
For OLED the L50 is used.

As a general guideline, LEDs designed for lighting applications often offer L70 values ranging from 50,000 to 60,000 hours. However, the introduction of cost-effective designs, such as those with plastic bodies or non-metal core PCBs, as well as space-constrained driver circuits, has resulted in LED lifetimes of 10,000 to 30,000 hours. These lifetimes are now more comparable to those of traditional lighting sources in terms of price and performance.

It's important to note that these figures are estimates and can vary depending on various factors such as operating conditions, temperature, and quality of the LED components. Consulting the manufacturer's datasheets and considering the specific application requirements are crucial when selecting LEDs to ensure they meet the desired lifespan and performance expectations.
For OLEDs, L50 is commonly used, representing the time at which they produce 50% of their initial lumens. L70 is typically used for general illumination applications, while L50 may be more appropriate for decorative applications where the exact quantity of lumens is less critical.

A lamp life of 50,000 hours, for example, corresponds to approximately 11 years of operation when used for 12 hours per day. Manufacturers employ modeling techniques to predict characteristics such as lumen maintenance, shift in dominant wavelength, and lamp life based on the hours of operation. The rapid development of LED products has made it necessary for manufacturers to utilize such modeling to provide estimations of product performance over time.

28.2 Rated Lamp Life

The ranges for typical lamp life in hours for various electric light sources and lamp life versus dimming trends are shown in Fig. 46. All ranges are for full lumen output. Dimming may increase, decrease, or have no effect on lamp life.

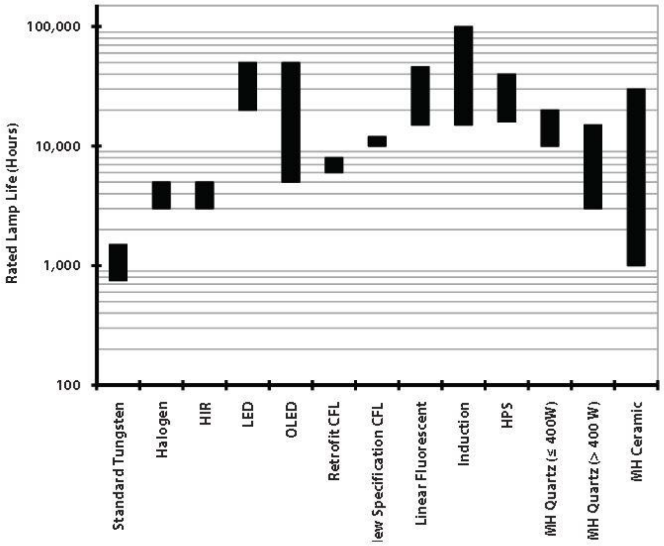


Fig. 46 LED Lifetime Estimate with LM80 and TM-21

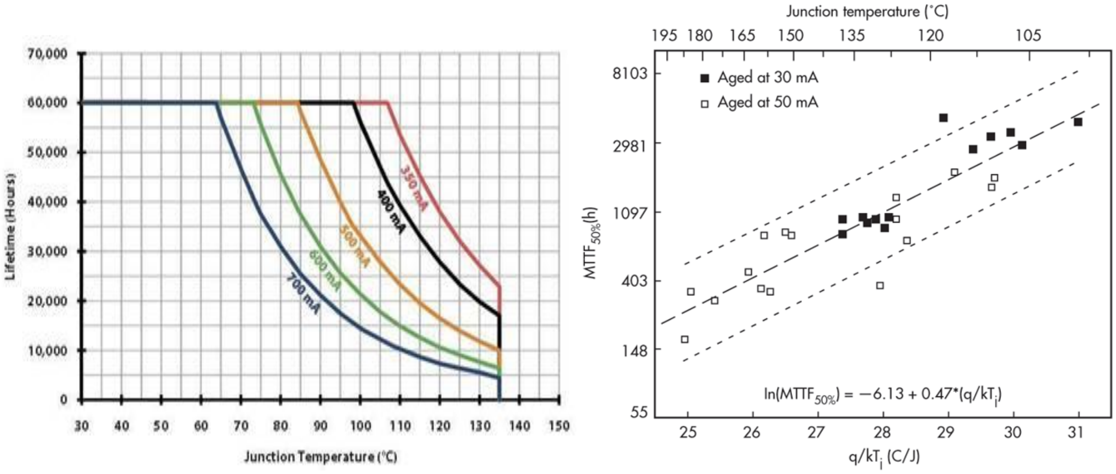
In 2008, the Illuminating Engineering Society (IES) published the LM-80 standard, which provides recommendations for testing LED lumen maintenance. This standard outlines procedures for testing the long-term performance of LEDs by measuring their lumen maintenance over a specified period of time. Three years later, the IES published TM-21 as a complementary document to LM-80, which offers a method for projecting the long-term lumen maintenance of LEDs based on the data collected from LM-80 testing.

LM-80 specifies the test duration, which is typically 6,000 hours or 10,000 hours. It also originally required a minimum of three case temperatures (55°C, 85°C, 105°C) to be tested. However, in the current version of LM-80, the requirement for a minimum of three case temperatures has been removed. This change aligns with the TM-21 instruction, which recommends collecting data for two case temperatures in LM-80 testing.

TM-21 provides guidance on how to extrapolate the lumen maintenance data collected from the LM-80 tests to project the long-term performance of LEDs. The test duration used in LM-80 directly influences the total projection period. For example, if a six-time multiplier is used, the projection period would be 60,000 hours for 10,000-hour test data and 36,000 hours for 6,000-hour test data. TM-21 clarifies that when there are uneven length test durations, the projection should only be based on the test data set with the shorter duration.

The mathematical formulas and empirical data models developed by the TM-21 working group are based on the physics of LED structures and materials. These models are used to exemplify the lumen decay behavior of LEDs and aid in projecting their long-term lumen maintenance performance.

Overall, LM-80 and TM-21 have become widely accepted and used by LED manufacturers, testing laboratories, and government specifications. These documents have helped establish consistency in the industry regarding LED lumen maintenance information and projections, facilitating better understanding and evaluation of LED performance over time.



.

Fig. 47 a) LED Life Time LED Vs Junction Temperature (^{O}C) For Different Drive Current
B) MTTF Vs Junction Temperature

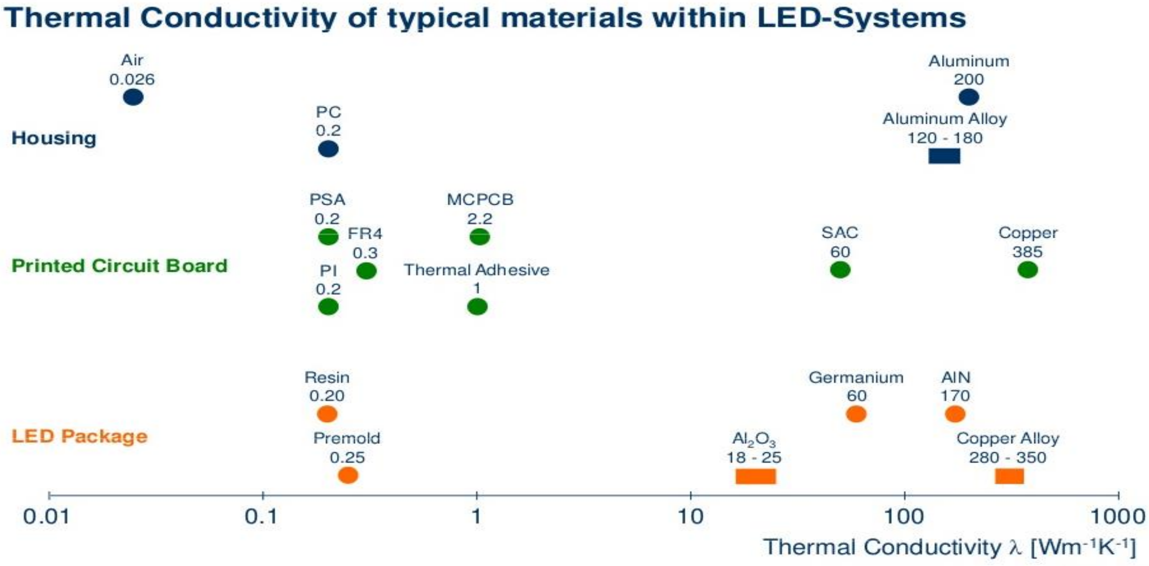


Fig. 48 Thermal Conductivity of Materials related to LED system

Knowing the thermal conductivity as shown in Fig.48 for different heat sink materials and that of LEDs designer to decide what type to be used for the product design.

28.3 Lamp Life

The LED packages with better thermal path make huge difference in the life time as seen in 5mm versus power package LED.

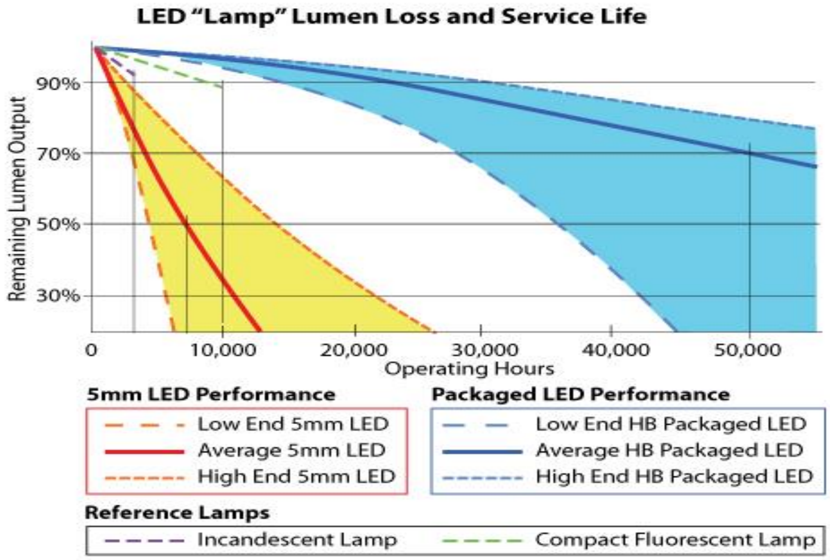


Fig. 49 Lumen maintenance of 5mm LED, Incandescent, CFL and Packaged Power LED.

28.4 Factors Affecting LED Lifespan

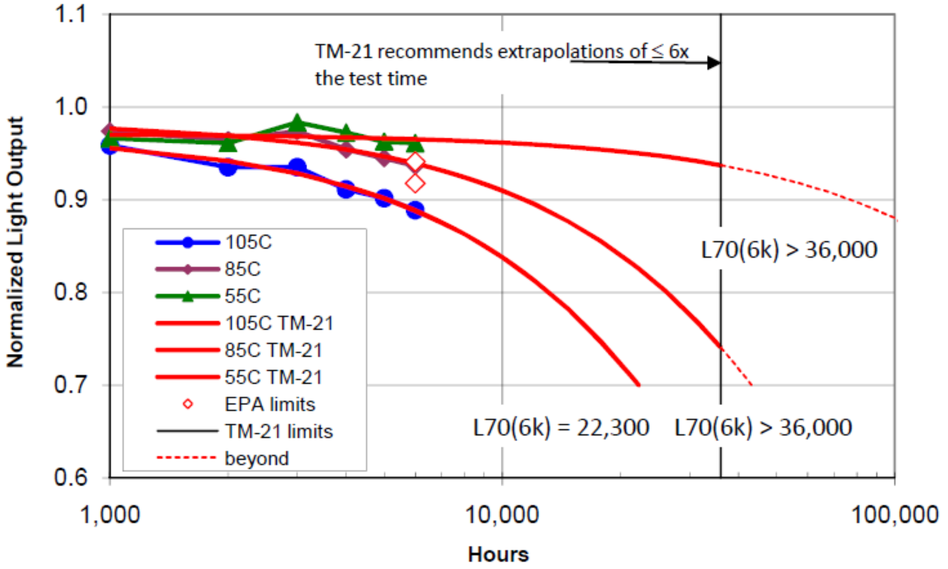


Fig. 50 Typical Lumen Maintenance at 55^{O}C, 85^{O}C, 105^{O}C as Performed in LM80 Test

Temperature is indeed a critical factor that significantly affects the useful lifetime of an LED. Excessive heat can dramatically reduce the lifespan of an LED, while proper thermal management can help maintain optimal performance and longevity.

To prevent the LED chip from operating at high temperatures, several elements can be incorporated into the design:

Heat Sinks or Heat Spreaders: These components help dissipate heat away from the LED chip by providing a larger surface area for heat transfer. Heat sinks are typically made of materials with high thermal conductivity, such as aluminum or copper, and are designed to efficiently dissipate heat into the surrounding environment.

Thermal Interface Materials (TIMs): TIMs, such as thermal pastes or pads, are used between the LED chip and the heat sink to enhance heat transfer. They fill any air gaps or irregularities between the surfaces, improving thermal conductivity and reducing thermal resistance.

Efficient Enclosure Design: The overall design of the luminaire or lighting fixture should facilitate proper airflow and heat dissipation. Well-designed enclosures may include ventilation holes, fins, or other features that promote the efficient removal of heat from the LED and surrounding components.

Thermal Management Systems: In some cases, active cooling methods such as fans or liquid cooling systems may be employed to maintain optimal operating temperatures for the LED.

By effectively managing temperature through these measures, the LED chip can be kept within its recommended temperature range, maximizing its useful lifetime. It's important to note that even a small temperature difference, such as a 10°C variation, can have a significant impact on the LED's lifespan, potentially extending or reducing it by thousands of hours.

Overall, careful consideration of thermal management in LED design and application plays a vital role in ensuring the maximum lifespan and optimal performance of the LED.

28.4.1 *Good thermal path from LED chip to mount*

In LED lighting systems, effective heat dissipation is crucial to ensure the longevity and optimal performance of the LED semiconductor. The heat generated by the LED should be efficiently transferred from the chip to the internal heatslug, PCB track (via solder or thermal interface material), aluminum core, and external metal body acting as a heatspreader or heatsink. Proper thermal management is particularly important in LED lighting applications where lamps are often instalLED in small light fittings that may not facilitate adequate cooling. Inadequate heat dissipation can lead to a reduction in LED lifetime.

Another factor to consider is the drive level of the LED. To maximize the LED's lifetime, it should be operated well within its specified ratings. Overdriving the LED can significantly decrease its lifespan, although it may increase the light output. It is important to adhere to the LED's recommended operating conditions.

The power supply or LED driver also plays a critical role in LED performance and lifespan. It should be a constant current type to ensure that the LED operates within its ratings and not too close to its maximum limits. High-quality LED drivers often include features such as high-temperature cutoff, protection against voltage fluctuations (e.g., in rural areas), surge protection, low total harmonic distortion (THD), high efficiency (above 85%), and power factor (PF) of 0.9 or higher.Deatils has been covered in section 2 of the same part 3.

Environmental factors can also impact LED lifetime. Conditions such as humidity, vibration, and extreme temperatures, even when the LED is not operating, can impose mechanical stresses on the luminaire and the LED, leading to reduced longevity.

While maximizing LED lifetime is generally desirable, there may be situations where other factors take precedence. For example, in some cases, light output may be more important than LED lifetime, and overdriving the LED to achieve higher brightness may be acceptable. Additionally, budget limitations may require a trade-off between LED life expectancy and cost.

Datasheets of LED products typically provide specifications related to these factors, and it is important to carefully consider all the parameters to ensure the LED is suitable for the intended application and provide a good margin for variations within the specified values.

28.4.2 *LEDs and their Potential Health Impact*

While there have been concerns about the increased content of short wavelengths, particularly blue light, in white light LEDs compared to traditional light sources like high-pressure sodium (HPS), it's crucial to consider the broader context and the unique capabilities that LEDs bring.

LEDs offer several advantages beyond their high energy efficiency and long lifetimes. One significant advantage is the ability to engineer their spectral content, allowing for customization and control over the emitted light. This intrinsic characteristic of LEDs enables the potential benefits of features like dimming and dynamic alteration of spectral output. No other outdoor lighting technology has offered such practical and versatile capabilities to the same extent.

By leveraging these capabilities, LED lighting systems can be designed and optimized to minimize potential health impacts. Through careful engineering of the spectral output, it is possible to reduce the amount of blue light without compromising other lighting qualities. This can be achieved by using phosphor coatings or other methods to tune the spectrum and create warmer or more visually comfortable light.

Additionally, the compatibility of LEDs with controls further enhances their potential for customization and optimization. With advanced lighting control systems, LEDs can be dimmed, adjusted, and even synchronized with natural lighting patterns or specific user requirements. This flexibility allows for greater adaptability and responsiveness in meeting lighting needs while minimizing potential health concerns.

It is essential to approach the topic of LED lighting and its potential health impacts with a balanced understanding of the capabilities and possibilities that LEDs offer. Details of hazards of lighting in chapter 15 .By leveraging the inherent advantages of LEDs and utilizing proper engineering and control strategies, it is possible to achieve efficient, long-lasting, and health-conscious lighting solutions for various applications.

29 BLUE LIGHT EFFECT ON HUMAN CIRCADIAN RHYTHM

Here are some key points to consider:

a) Blue Light Hazard for Circadian Disruption: When assessing the potential impact of a light source on circadian rhythm disruption, several factors come into play. These include the intensity of the blue light, duration of exposure, timing of exposure (especially during the evening and night), and the spectral power distribution (SPD) of the light source. These criteria help determine the potential effects on melatonin suppression and circadian regulation.

b) Blue Light Hazard for Retinal Damage: Evaluating the risk of retinal damage from blue light exposure involves additional factors beyond just color temperature. Parameters such as the size of the light source, intensity per unit area on the retina, and the SPD of the light source play crucial roles. The specific characteristics of the light source and its impact on the retina need to be considered for a comprehensive assessment of potential hazards.

c) Disability Glare and Discomfort Glare: It's important to distinguish between disability glare and discomfort glare. Disability glare refers to the glare that impairs visual performance, while discomfort glare is the sensation of glare that causes visual discomfort. Disability glare is not directly linked to the SPD of the light source, as stated in the AMA paper, but discomfort glare can be influenced by short wavelengths, including blue light.

d) Color Temperature and Circadian System: Color temperature alone is not a sufficient measure to determine the impact of a light source on the circadian system and melatonin production. Color temperature provides an indication of the warmth or coolness of light, but it does not provide complete information about the SPD. For instance, certain 3000K LEDs may have a greater impact on the circadian system and melatonin suppression compared to some 4000K LEDs if their SPDs contain a significant amount of blue light.

In summary, assessing the effects of blue light on human health and well-being requires considering various factors beyond color temperature. The intensity, duration, timing of exposure, and the SPD of the light source are critical factors to evaluate potential hazards related to circadian disruption and retinal damage. Complete spectral information is essential to make informed decisions about lighting design and minimize potential risks associated with blue light exposure.

30 REDUCING POTENTIAL IMPACT FROM SHORT-WAVELENGTH CONTENT

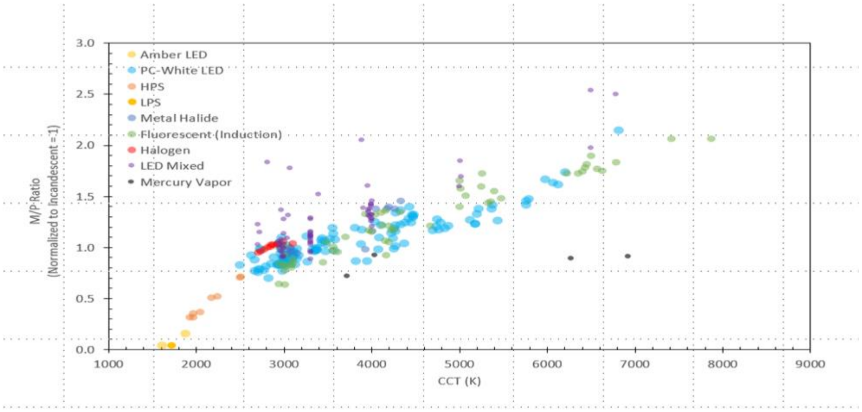


Fig. 51 Melanopic content & CCT of various Light Sources

Highlighted some important points regarding the reduction of the blue spectrum content in lighting. Indeed, there are multiple approaches to achieve this, including replacing the lamp with a lower correlated color temperature (CCT) or dimming the light output. Both methods can contribute to reducing the melanopic content, which has implications for human circadian rhythm and visual comfort. Refer Humen centric lighting chapter 11.

Substituting a higher CCT LED with a lower CCT LED is a straightforward approach to reduce the blue spectrum content. By replacing a 4000K LED with a 3000K LED, there is an averaged reduction in melanopic content of 11.5%. This reduction is achieved by considering the specific spectral power distribution (SPD) of each LED. It's important to note that the actual reduction in melanopic content will depend on the SPD of the new light source.

Dimming the lights offers additional advantages in addition to reducing the blue spectrum content:

Reduction in Energy Use and Cost: Dimming the light output of a luminaire directly reduces energy consumption. By dimming the lights by a certain percentage, energy use is correspondingly reduced, leading to cost savings in operation.

Longer Product Life: Dimming the lights can extend the lifespan of the LED luminaire. Operating the LEDs at a lower output reduces the stress on the components, potentially resulting in longer product life and reduced maintenance needs.

Addressing Brightness Complaints: Dimming can be an effective solution to address complaints related to excessive brightness or over-lighting. By adjusting the light output, the perceived brightness can be optimized according to individual preferences or specific requirements in a given environment.

Dimming can be applied to a range of dimming levels, including reducing the light output all the way to 100% dimming during certain periods, such as nighttime when lower light levels may be desirable from a circadian perspective.

It's worth noting that combining the approach of substituting a lower CCT LED with dimming can yield even greater reductions in melanopic content, depending on the specific requirements and desired lighting outcomes.

In summary, both replacing the lamp with a lower CCT LED and dimming the lights offer viable strategies to reduce the blue spectrum content and optimize lighting conditions. Each approach has its own distinct advantages, and their combination can provide further customization and flexibility in achieving desired lighting goals.

LED technology has been evolving rapidly, and various types of LEDs and alternative light sources are gaining popularity for different applications.

UV LEDs have found their niche in applications such as sterilization, water purification, and medical equipment. They provide a compact and energy-efficient solution for generating ultraviolet light or UVGR applications. Refer chapter 18 for details of UVGR.

Organic LEDs (OLEDs) offer unique advantages, including flexibility, thinness, and the ability to create curved or transparent displays. Their form factor versatility has opened up new possibilities for lighting and display designs. While OLEDs have slightly lower efficacy compared to traditional LEDs, advancements in materials and manufacturing processes continue to improve their efficiency.

Laser diodes have found extensive use in applications such as telecommunications, laser pointers, and optical storage devices. They generate coherent and concentrated light, enabling precise control and focused beam applications

Light-emitting plasma (LEP) is a relatively new light source that offers high colour rendering capabilities and a wide colour gamut. LEP technology combines the benefits of plasma and LED technology to create a unique lighting experience. It has potential applications in architectural lighting and stage lighting.

The shift from incandescent to gas discharge and now to solid-state lighting (LEDs) has indeed been a significant transformation in the lighting industry. Solid-state lighting has revolutionized energy efficiency, durability, and design flexibility. With ongoing advancements in LED technology, we can expect further improvements in efficiency, colour quality, and lifespan

As technology continues to evolve, it is essential to stay updated and adapt to these advancements. The lighting industry is experiencing an exciting phase with endless possibilities for innovation and creative applications. Embracing these changes and exploring the potential of emerging light sources can lead to transformative solutions in various fields, including illumination, communication, healthcare, and beyond.

Indeed, interesting days lie ahead as we witness the ongoing evolution and convergence of light source technologies which will lead to have this NLC revision.

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

(Not to be reproduced without the permission of BIS or used as a Part of National Lighting Code of India)

Draft NATIONAL LIGHTING CODE OF INDIA

PART 3 Electric Light Sources & Their Accessories

Section 2 LED Driver and Controls

[First Revision of SP 72 (Part 3/Section 2)]

Illumination Engineering and Luminaries Sectional Committee, ETD 49	**Last Date for Comments: _____**

FOREWORD

In recent years, there has been a significant revolution in lighting technology, with traditional filament lamps and discharge lamps being replaced by LEDs (light-emitting diodes) in various lighting applications. LEDs have become an integral part of modern lighting systems and are always driven by LED drivers to produce light. The LED driver is often referred to as the "heart" of the lighting system because of its crucial role in the performance of LEDs, similar to how the heart functions for humans.

LED drivers are electronic devices that utilize semiconductors to control and supply direct current (DC) power for starting and operating LEDs. As energy regulations have become more stringent, many people are now familiar with the long lifespan and energy-saving benefits of LEDs. However, it is important to note that these innovative light sources require specialized devices called LED drivers to operate effectively. LED drivers, also known as LED power supplies, serve a similar purpose as ballasts for fluorescent lamps or transformers for low voltage bulbs. They provide the necessary electrical power to LEDs, enabling them to function and perform optimally.

In the realm of digital addressable lighting, DALI (Digital Addressable Lighting Interface) systems encompass both LED drivers and controllers. DALI is widely used in both traditional lighting and LED lighting applications, providing advanced control and flexibility for lighting installations.

Overall, LED drivers are essential components in modern lighting systems, ensuring efficient operation and performance of LEDs, and enabling the realization of energy-efficient and long-lasting lighting solutions.

Key functions of a LED driver:

LED drivers serve several key functions in a lighting system. These functions include:

a) Voltage and Current Conversion: LED drivers are responsible for converting the incoming mains voltage into the appropriate voltage and current levels required by the LED module. This conversion is crucial to ensure that the LED module operates within its specified operating range, preventing any potential breakdown or damage to the LEDs.
b) Dimming Control: LED drivers often incorporate dimming capabilities, allowing users to control and adjust the brightness or intensity of the LED lighting. This dimming control enables users to regulate the amount of light output according to their needs, providing flexibility in creating desired lighting atmospheres and also helping to save energy by reducing power consumption when lower light levels are sufficient.
c) Safety and Performance Optimization: LED drivers play a vital role in addressing safety and performance issues associated with LED lighting. They are designed to ensure electrical and mechanical safety, protecting the LEDs and the entire lighting system from potential hazards such as overvoltage, overcurrent, and short circuits. LED drivers also optimize electrical performance by providing stable and consistent power supply to the LEDs, helping to maximize their efficiency and longevity.

By fulfilling these key functions, LED drivers enable the efficient and reliable operation of LED lighting systems, ensuring optimal performance, energy efficiency, and safety. They are an essential component in achieving the benefits of LED technology in various lighting applications.

1 SCOPE

This chapter serves as an introduction to LED drivers, covering their fundamentals, types, operating characteristics, classifications, specifications, applications, and DALI controls (excluding other digital control methods). The goal is to provide a comprehensive understanding of LED drivers for LED devices, arrays, or systems used in general lighting applications.

The chapter includes information on the selection criteria for choosing an appropriate LED driver based on specific application requirements. Factors such as voltage and current compatibility, power rating, efficiency, dimming capabilities, and safety considerations are discussed to aid in driver selection.

Furthermore, the chapter delves into the control aspects of LED drivers, particularly focusing on dimming control. Dimming functionality allows users to adjust the light output of LED luminaires, providing flexibility in creating desired lighting atmospheres and optimizing energy consumption.

By covering the basics of LED drivers, their various types, operating characteristics, classifications, specifications, and applications, this chapter aims to equip readers with the necessary knowledge to understand and select suitable LED drivers for their lighting projects.

2 REFERENCE

IS No.	***Title***
IS 14700 (Part 3/Sec 3): 2018	Electromagnetic compatibility (EMC): Part 3 limits Section 3 limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply system, for equipment with rated current 16 a per phase and not subjected to conditional connection (Second Revision)
IS 14700 (Part 4/Sec 15): 2018	Electromagnetic compatibility (EMC): Part 4 testing and measurement techniques: Sec 15 flickermeter - Functional and design specifications (Second Revision)
IS15885 (Series)	Safety of lamp controlgear
IS 16101:2012	General lighting - LEDs and LED modules - Terms and definitions
IS 16102 series	Self ballasted LED lamps for general lighting services
CISPR 15:2018	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
IEC TR 61547-1:2020	Equipment for general lighting purposes - EMC immunity requirements - Part 1: Objective light flickermeter and voltage fluctuation immunity test method

EN 55022	Information Technology Equipment – Radio disturbance characteristics – Limits and methods of measurement
ANSI C82.16-2022	Light-Emitting Diode Drivers

3 TERMINOLOGY

3.1 LED Driver

Electronic circuit that converts the mains into the right voltage and current for the LED module.

3.2 Ballast

Big coil used for conventional HID and TL lighting.

3.3 Electronic ballast

Electronic circuit used for HID and TL lighting.

3.4 Converter

DC-DC converter or AC-AC most times input is higher or lower than the output.

3.5 Inverter- DC-AC converter.

3.6 Transformer

Voltage transformer, Current transformer.

3.7 THD_I (%)

Total Harmonic Distortion (0% - 100%) of the driver input current.

It is a measure of how close the current waveform is to a pure sine wave. The THD of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

3.8 Power Factor (PF = cos φ)

The Power Factor (0 - 1) is the ratio between real power and apparent power.

This unitless value describes how much the current is in phase with the voltage. An ideal resistor load has a power factor of 1.

$$PF (\cos \varphi) = \text{Real Power} / \text{Apparent Power}$$

In fact for a non linear load the power factor is a combination of displacement power factor and distortion power factor. The relation can best be described as follows:

$$pf_{true} \le pf_{displacement} = \frac{1}{\sqrt{1+\left(\frac{THD_I}{100}\right)^2}}$$

3.9 Efficiency (%)

The efficiency is the ratio between output power and input power. High efficiency is hard to get at low output power, because the fixed losses (to make the desired function) are dominant. η = Pout / Pin

3.10 T Case (°C)

Temperature at a certain test point on the driver casing. When this test point has reached maximum specified T case temperature, the rated lifetime is reduced to 50%. A luminaire builder will use this spot to determine the expected lifetime of the luminaire.

3.11 Isolated Driver

Driver with isolated output from the supply mains by means such as a safety isolating transformer or converter with separate windings

3.12 Non-Isolated Driver

Driver with no isolated output. It contains conductive parts which may cause an electric shock in normal use.

3.12 CC

A constant current LED driver maintains a steady output LED current at different LED voltages. This provides the optimum operation for LEDs to reach the possible long life.

3.13 CV

A constant voltage supply will regulate a certain output voltage. Not used for direct connecting LEDs.

3.14 MCB

Miniature Circuit Breaker: rated current not more than 100 A. 16A type B often used.
Many different classifications of circuit breakers can be made, based on their features such as voltage class, construction type, interrupting type, and structural features.

3.15 Electronic Transformer

Electronic HF circuit with small transformer inside.

3.16 Controllable Driver/Ballast

Driver/ballast that controls, manages, commands, directs or regulates the behaviour though power delivered to a light source between a minimum/off value and a maximum value according to a signal on its control terminals **PWM, DALI, 1-10V, etc.**

4 BASICS OF LED DRIVER

4.1 What is an LED Driver

An LED driver is the electronic device which regulates the power to LED's. LED stands for Light emitting diode. When power flows through LED, Holes from the P-region and electrons from N-region are shoot up into the P-N junction. They get mixed with each other to generate Photons which is purely visible light. The process of conversion from power to visible light is virtually linear, rise in the power lets more electrons and holes mixed in the P-N junction and therefore more visible light is produced.

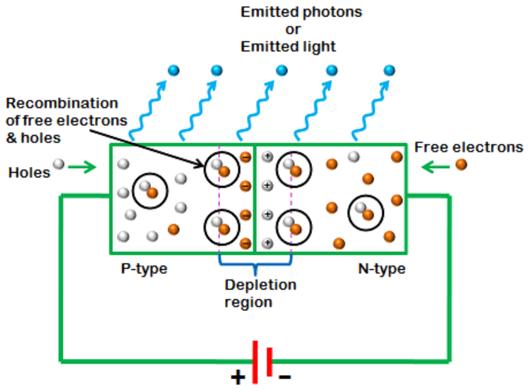


Fig. 1

Conventional lamps used to work on AC power directly, LED's operate on DC power. If LED's are forced to work on AC then It will produce light only when the AC signal is in positive half cycle of the AC waveform, as LED have polarity.

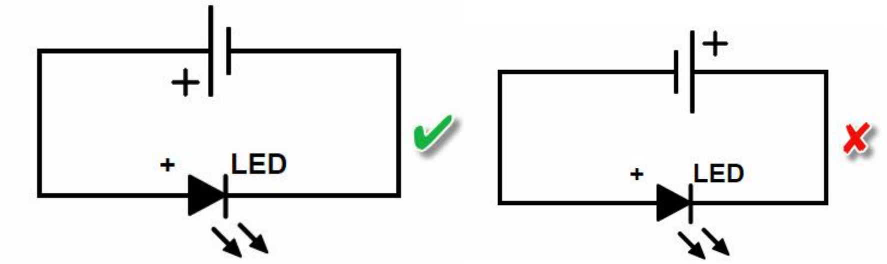


Fig. 2

LED driver act as converter between AC power source and LED’s, converting incoming AC power 230V, 50Hz to the regulated DC power required to drive LED’s. There are drivers designed to take inputs of other type of power source like DC Battery and POE (Power Over Ethernet). The LED driver is not just a Power converter. It should handle the Voltage fluctuations, noise on the AC Power and harmonics in the input to avoid unwanted effect in driver output. Any effect in driver output will eventually affect the light output. Latest LED drivers provides additional integrated circuit technology to help the precise control of the light output.

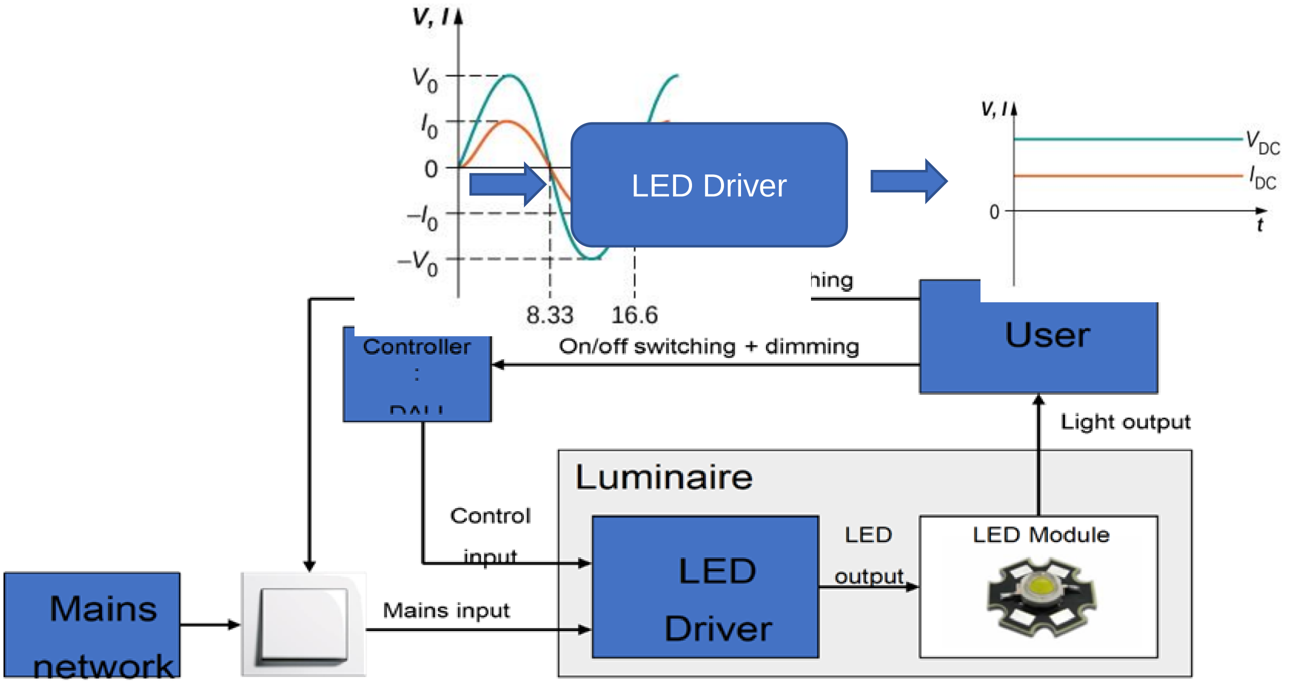


Fig.3

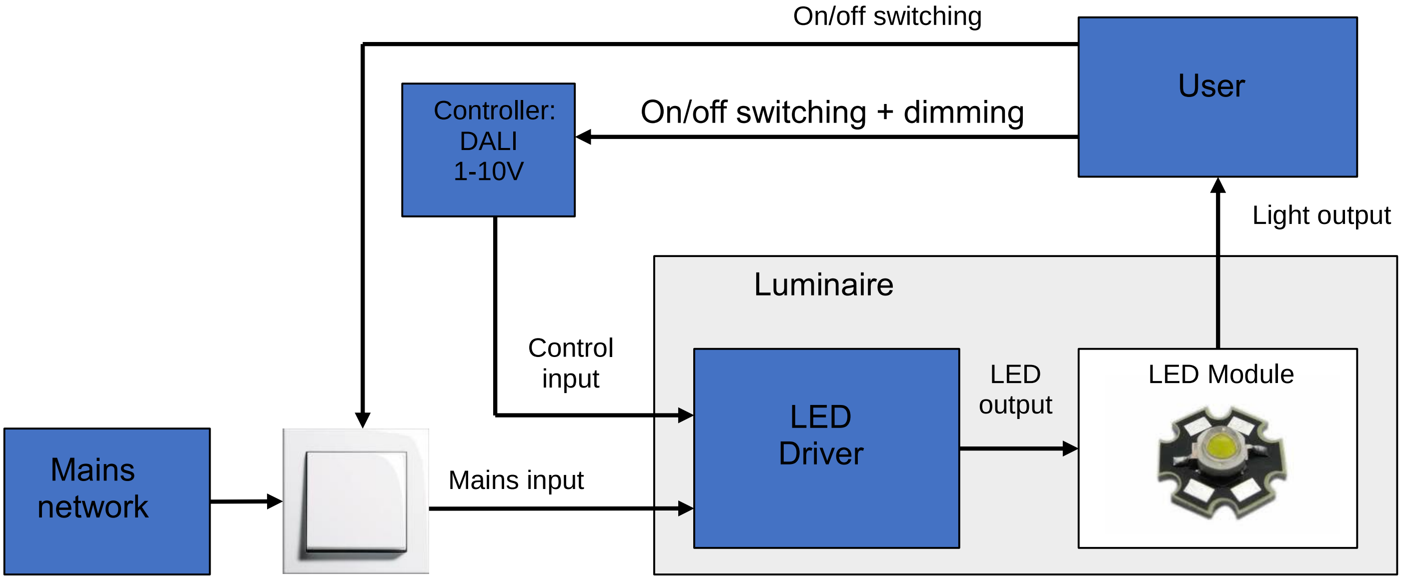


Fig.4

In Summary, LED Driver converts High Voltage AC current to Low Voltage DC current So that the LED’s can be driven with their respective forward voltage and current.

4.2 Types of LED Driver

An electronic device that converts the incoming power to a constant-voltage DC output has been referred to as a Power supply, whereas an LED driver is been denoted to an electronic device that provides a constant current DC output. Today, "LED driver" and "LED power supply" are very unclear terms that are being used interchangeably. Despite the terminological uncertainty, we can't afford to neglect the basic differences between the constant current (CC) and constant voltage (CV) circuits.

4.2.1 *Constant Current LED Driver*

Constant current LED drivers deliver a constant current (e.g., 350mA, 500mA, 700mA, or 1A), irrespective of the load voltage, to an LED module within a specific voltage range.

The CC LED driver can drive a single module with LEDs connected in series or multiple LED modules connected in parallel. Series connection is preferred in CC circuit because it ensures all the LEDs have the same current flowing across their semiconductor junctions and the light output is unvarying across the LEDs. However, this limits the no. of LED’s can drive on single driver output.

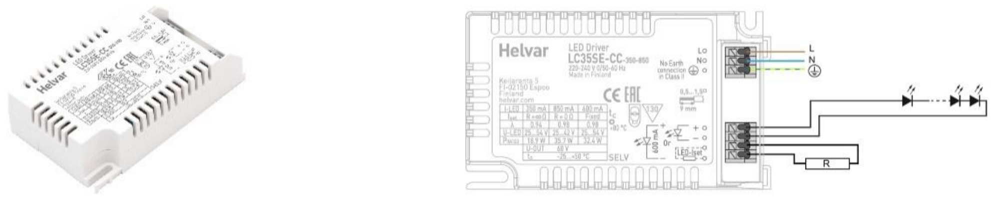


Fig. 5

Constant current LED drivers are used when light output should be independent of the input voltage fluctuation. They are mainly used in lighting products such as down lights, linear profiles, table/floor lamps, pendants, street and high bay lights. These Lighting products requires precise constant current output from LED driver.

CC drivers support both pulse-width modulation (PWM) and constant-current reduction (CCR) dimming. Operating a power supply in a CC mode usually requires overvoltage protection just in case an excessive load resistance is encountered or when the load is disconnected.

4.2.2 *Constant Voltage LED Driver*

Constant voltage LED drivers are designed to drive LED’s at a fixed voltage, typically 12V or 24V.

It is generally preferred to provide a constant voltage supply to multiple LED modules or string of LED’s connected in parallel. Parallel connection is preferred in CV circuits because it ensures all the LEDs have the same voltage flowing across their semiconductor junctions.

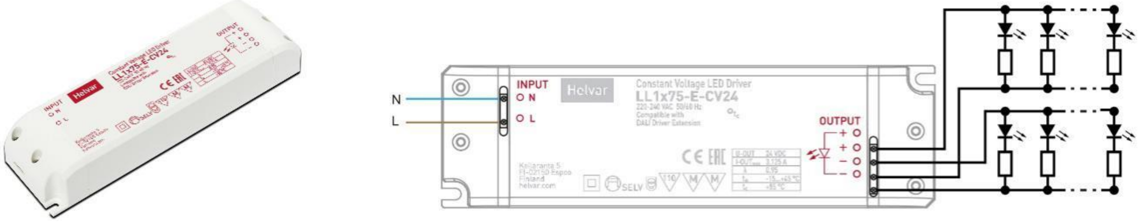


Fig. 6

CV drivers are often used in low voltage LED lighting applications that requires large no. of small power LED’s to be connected to a single driver output. e.g. LED strip lights, LED signages. Constant voltage drivers can only be PWM dimmed.
The CV driver must sustain the power dissipation when the load goes short circuit. The current limiters typically have thermal shutdown to protect the circuit when a voltage higher than the max. Suitable voltage is placed across the current limiter.

4.2.3 *AC LED Driver*

The purpose of AC LED driver is to convert 230V AC Voltage to 12/24 V DC AC Voltage. Mainly used to power the internal driver of retrofit LED lamp. The Internal driver of LED lamp will convert the low Voltage AC to desired DC Voltage.

Fig.7

4.3 Switch Mode Power Supply (SMPS)

As LEDs are very sensitive to current and voltage fluctuations, one of the most important roles of an LED driver is to decrease variations in forward voltage across the semiconductor junction of the LEDs.

Switched-mode power supplies operate by modulating an electrical signal using one or more switching elements such as MOSFETs at a high frequency. Thus generating the fixed magnitude of DC power under supply voltage or load variations. Switch-mode converters used in LED drivers require energy to be stored as current using inductors and as voltage using capacitors so as to maintain the output current or voltage on the load during the on/off switching cycle. An AC-DC SMPS LED driver rectifies AC power into DC power which is then converted into DC power capable of driving the LEDs.

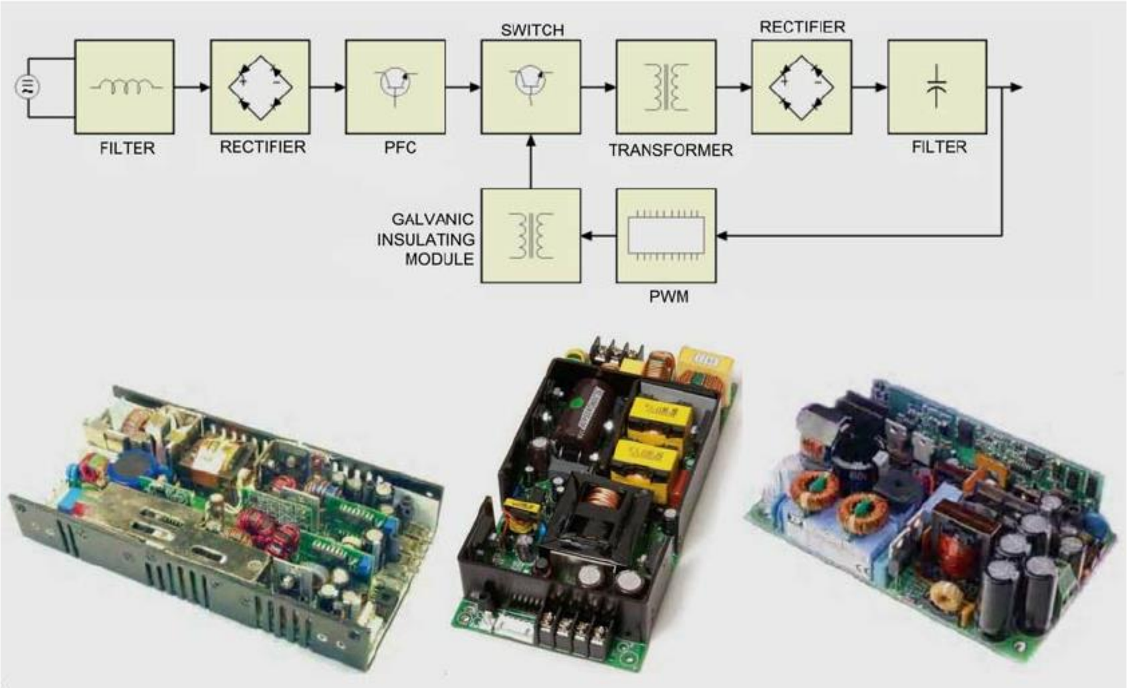


Fig.8

For the switched-mode power conversion in LED drivers, various circuit topologies are available to support the LED load requirements. Among all SMPS topologies, buck, boost, buck-boost, and flyback are the most commonly used types.

4.3.1 *Buck Circuit Topology*

Also known as a step-down converter, a buck circuit regulates input DC voltage down to a desired DC voltage using a number of current control methods, including synchronous switching, hysteretic control, peak current control, and average current control. The buck topology is designed for mains-powered LED drivers which are required to drive a long string of LEDs, with the load voltage kept under the supply voltage. Buck circuits are also frequently found in low voltage applications where the input supply voltage is relatively low (e.g., 12 VDC for automotive lighting) and just one LED is being driven.

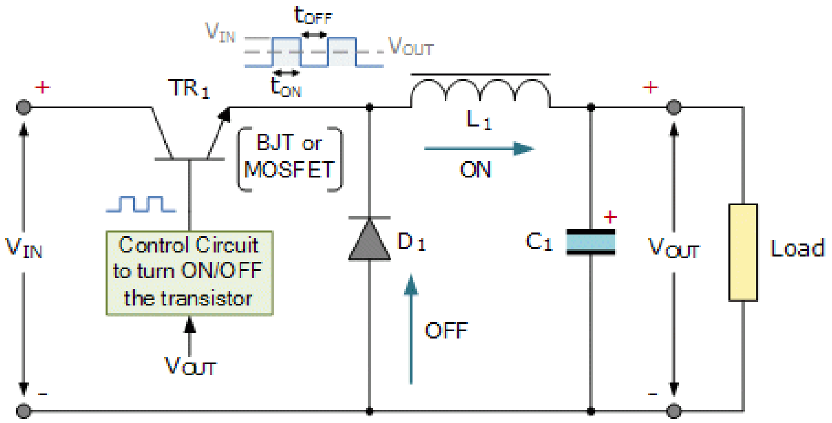


Fig. 9

The buck topology allows for circuit design with fewer component counts while maintaining a high efficiency (90–95%). However, the load voltage of a buck circuit must be less than 85% of the supply voltage. Moreover, buck LED drivers do not offer isolation between the input and output circuits.

4.3.2 *Boost Circuit Topology*

A boost converter is designed to step up the input voltage to a higher output voltage by about 20% or more.

Boost circuits generally require one inductor and operates in either the continuous conduction mode (CCM) or discontinuous conduction mode (DCM), as determined by the waveform of the inductor current.

Low-power boost converters can use a charge pump, rather than an inductor, which uses capacitors and switches to raise the output voltage above the supply voltage. Inductor-based converters offer the advantage of low component counts and high operational efficiencies (greater than 90%).

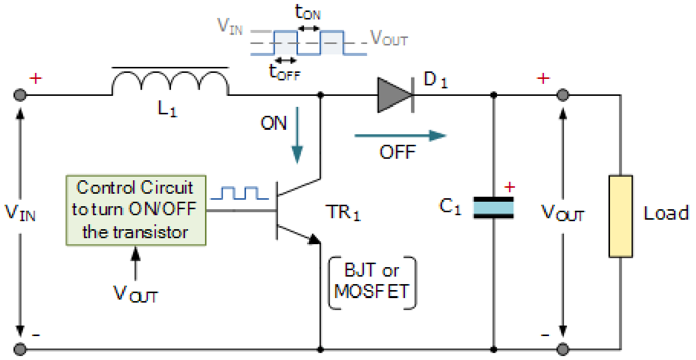


Fig. 10

The disadvantage of this topology is that it offers no isolation between the input and output circuits. Boost converter outputs a pulsed waveform and thus requires a large output capacitor to reduce the current ripple. PWM dimming is challenging with the large output capacitor as well as the closed-loop control which demands a large bandwidth to stabilize the converter.

4.3.3 *Buck Boost Topology*

Buck-boost converters can provide an output higher or lower than the input voltage, making them ideal for applications where the input voltage rises and falls with a large variation (no more than 20%). Input voltage fluctuations of this type usually occur in battery-powered lighting applications, e.g., vehicle-mounted lighting for construction and agricultural machinery (forklifts, tractors, harvesters, diggers, snow ploughs, etc.) as well as trucks and buses.

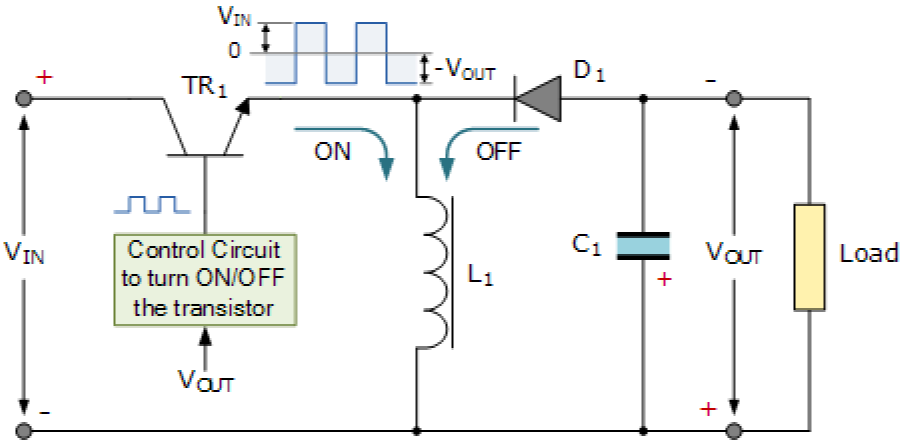


Fig.11

Two types of converters often found in buck-boost applications are known as SEPIC (single-ended primary inductance converter) and Cuk.

The SEPIC converter is characterized by the use of two inductors, preferably a dual-winding inductor which has a small footprint, low leakage inductance, and the ability to increases the coupling of the windings for improved circuit efficiency. In a SEPIC architecture, the boost section provides power factor correction (PFC) and the buck section produces a voltage to be the same as, lower, or higher than the input voltage, while output polarity of both sections remains the same.

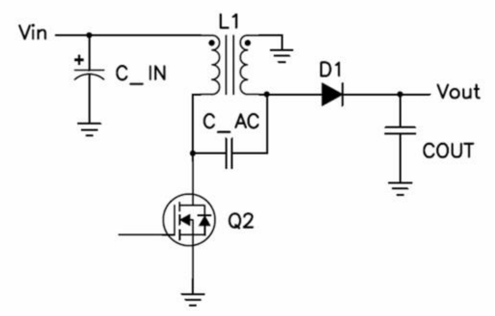


Fig. 12

The Cuk topology combines the continuous output current of a buck and the continuous input current of a boost, which gives the Cuk the best EMI performance and allows the capacitance to be reduced as needed. The buck-boost converter is a non-isolated driver circuit. Like boost converters, buck-boost converters require overvoltage protection to prevent damages from excessively high voltage in case of an open-load condition.

4.3.4 *Flyback Switching Topology*

A flyback switching circuit is a discontinuous conduction mode converter which provides AC mains isolation, energy storage, and voltage scaling. It is very much like a buck-boost converter, but with the inductor split to form a transformer.

The flyback transformer with at least two windings not only provides complete isolation between its input and output circuits, but also allows for more than one output voltage in different polarities. The primary winding is connected to the input power supply, the secondary winding is connected to the load. Magnetic energy is stored in the transformer while switch is on and at the same time the diode is reverse-biased (i.e., blocked). When the switch is off, the diode is forward-biased and magnetic energy is released by current flowing out of the secondary winding. Some flyback circuits use a third winding, called a bootstrap or auxiliary winding, to power the control IC.

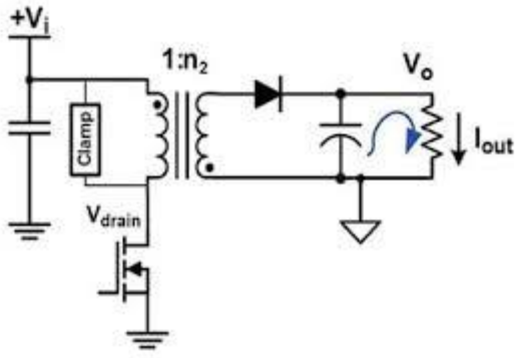


Fig.13

More accurate control of the average voltage across the capacitor, which is used to maintain current flow in the LED load when the converter is on the first step, requires isolated feedback, usually via an optocoupler. Flyback swiching circuits can be designed for a very wide range of supply and output voltages, with isolation from dangerously high voltages. However, these circuits are less efficient (75 - 85%, higher efficiency is possible by using expensive parts).

4.4 Linear Power Supply

A linear power supply uses a control element (such as a resistive load) which operates in its linear region to regulate the output. In this type of LED driving circuits, the voltage flowing through a current-sensing resistor is compared to the voltage reference in a feedback loop to produce the control signal. A controller which is operated in a linear region of the closed loop feedback system adjusts the output voltage until the current flowing through the sensing resistor matches the feedback voltage. The current delivered to an LED string is thus maintained if the forward voltage does not exceed the dropout-limited output voltage.

Linear drivers provide only step-down conversion, which means the load voltage must be kept lower than the supply voltage. If the load voltage is higher than the supply voltage or the supply voltage has a wide variation, a switching regulator is needed.

AC mains-powered applications, which has demanding requirement for voltage regulation, typically choose switched linear regulators to drive LED lamps with a long string of LEDs wired in series. Switched linear regulators are combinations of multiple linear regulators which are either integrated or cascaded in a modular form. Typically designed in surface-mount IC packages, these linear regulators are used to intelligently adjust the number of loads connected LED’s in a string during a power line cycle so that the load voltage matches the instantaneous AC mains voltage.

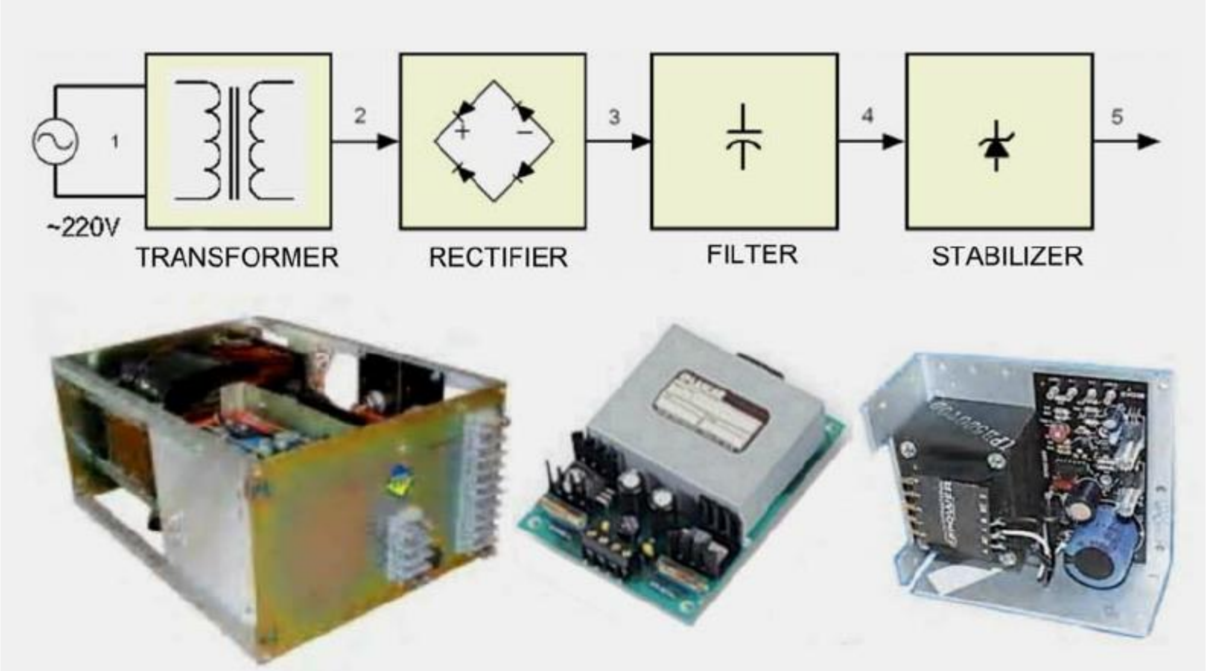


Fig. 14

Linear LED drivers provide an extremely simplified solution which eliminates the need for bulky and costly coils, capacitors, and the reactive (e.g., inductive and/or capacitive) input EMI/EMC filter elements. A significantly low parts count and the use of solid-state components allow the switched linear regulator to be downsized to a compact IC chip. This makes linear drivers a competitive candidate for LED lamps of which cost and physical size are important design considerations.

Characterized by its cost competitiveness, EMI/EMC immunity, small footprint and design simplicity, the linear driving topology is gaining a rising interest in the industry. However, linear drivers are struggling with their inherent disadvantages that hold them back from entering mainstream applications in quite a few product categories.

a) A linear LED driver can be of low efficiency, when the supply voltage runs substantially higher than the load voltage;

b) The excess power is released as heat energy, resulting increased thermal stress on the driver circuit and very likely on the LEDs as well if heat is not efficiently dissipated;

c) The limitation of having to keep the load voltage lower than the supply voltage within a certain range leads to a further shortcoming of only allowing a restricted supply voltage range;

d) Linear drivers available on the local market are dominantly low-cost circuits which give no special consideration on flicker elimination;

e) The low cost non-isolated topology provides no electrical isolation from the AC mains supply.

f)

4.4.1 *Switch Vs Linear*

The design of an LED driver involves many compromises. The selection between SMPS and linear drivers has to take cost, efficiency, control, lifespan, dimming, size, power factor, flicker, input/output, AC mains isolation, and various other factors into consideration.

Switching power supplies are obviously more efficient than the linear ones because of their "0/1" (ON/OFF switching) modulation. They can be designed to deliver high power efficiency as well as flicker-free illumination while maintaining a high power factor and low total harmonic distortion (THD).

While linear LED drivers have been envisioned potential LED driving solution, SMPS is, for the foreseeable future, still the preferred LED driving solution for applications where efficiency, lighting control, light quality, and electrical safety are of paramount concern. In particular, the digital controllability of SMPS drivers, which are equipped with smart sensor technology and wireless connectivity, promises to enable a variety of Internet of Things (IoT) applications.

Nonetheless, the captivating features of SMPS drivers are achieved at the expense of their dependence on bulky, expensive and unreliable reactive components, such as transformers, inductors, and capacitors. High-speed switching operation causes much noise, thus leading to a relative high level of electromagnetic interference which has to be filtered and screened using additional circuits. These additional circuits can tremendously increase the physical sizes and double the overall cost of the LED driver.

The largest disadvantage of SMPS drivers, which is also the most attractive feature of linear drivers, is their reliability. An SMPS driving circuit uses a large number of components including filters, rectifiers, power factor corrector (PFC) circuits, etc. The complex design may degrade circuit reliability. Widespread use of aluminium electrolytic capacitors in the PFC as an energy-storage component introduces the biggest concern about the reliability of an SMPS driver. Electrolytic capacitors are known for their high-capacitance value and high-voltage rating. Nevertheless, the electrolyte in the capacitor will evaporate over time. The evaporation rate linearly correlates to temperature. High temperature will accelerate electrolyte evaporation, which causes a decrease in capacitance and an increase in ESR (equivalent series resistance). Increased ESR translates to high output voltage ripple and noise. And the capacitor eventually fails when electrolyte dries out, leading to the premature failure of the entire lighting system.

High-speed switching operation can produce electromagnetic interference (EMI) which adversely affects the surrounding circuit elements. This poses an additional design challenge to overcome. The uses of a noise filter lead to an increase in volume and weight as well as manufacturing cost.

On the other side, linear drivers do hold a great potential owing to the previously mentioned advantages. They typically live longer than SMPS drivers, simplifies lamp design, and delivers cost, and reduce the BOM significantly. Earlier considered as challenge, Nowadays linear driver are designed with higher conversion efficiency and flicker free comparable to SMPS circuits. This technology is currently used broadly. The majority of the lighting manufacturers consider it for applications like high quality light, AC mains isolation, electrical safety sensitive indoor lighting and where flicker free operation is required.

4.5 Driver on Board (DOB)

DOB is a typical implementation of the linear driving topology. Also called an AC LED light engine, the DOB LED module accommodates the LEDs and all the driver electronics on a metal-core printed circuited board (MCPCB). DOB technology takes advantage of the MCPCB-mountability of the high voltage driver ICs (switched linear regulators).

Unlike the SMPS driver circuitry which has to be mounted on a routed FR4 PCB, these surface-mount driver ICs can be soldered to the LED-mounted MCPCB without circuit routing. This eliminates entirely the need for a dedicated driver assembly and thus allows for a compact form factor.

Another benefit of DOB design is that the excellent thermal conductivity of the MCPCB can facilitate rapid dissipation of heat generated due to the inefficient conversion of a linear driver.

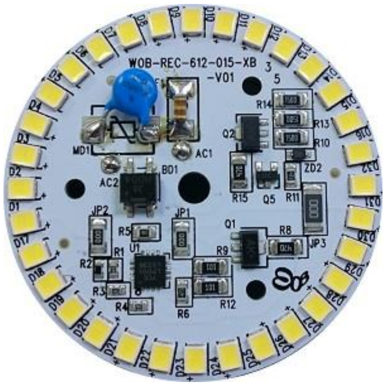


Fig.15

4.6 Emergency LED Driver

In the event of power failure, the lights should never go off completely. Especially in Public areas, it often causes a panic situation for occupants. For that reason, LED drivers are equipped with built in emergency battery and named as Emergency LED drivers. These drivers can work on both AC as well as DC input supply. During times when the mains power is on, the driver takes input supply from mains power (AC) and when the mains power is OFF, the drivers takes input supply from the battery. The battery is constantly restoring the charge in an ideal mode and release the charge in the event of mains power failure.

The battery should be maintenance free, quick charged within 24 hours and provide back up of min 1hr to 3 hr of duration.

Fig.16

5 TYPES OF DIMMABLE LED DRIVERS

The evolution from traditional lamps to LED’s is obsessed by the need for better energy efficiency, control and communication. One of the benefits of LEDs is the ability to respond instantly to changes in power input which is regulated by the LED driver.

Also, the price of LED is speedily decreasing despite the fact their efficacy is increasing day by day. Their efficacy is now competitive to conventional fluorescent lamps.
Nevertheless, the Lifespan of LED’s is significantly longer than 1,00,000 burning hours, Dimming LED’s will further extend their Life span. As Dimming the LED’s produces less heat, meaning lower junction temperature. In general, the lower the junction temperature, higher is the lifespan.
The non-dimmable LED drivers delivers constant light output throughout the operation and one cannot change the light output at desired level. However, the dimmable LED drivers offers the flexibility to user to regulate the light output from 100% to 1% or even less. The dimming performance of LED drivers is extremely important as lighting becomes more connected and adaptive towards user’s need and mood.
The dimming methods are continuously evolving from conventional Triac dimming to latest DALI dimming. Let’s understand each one of them in detail.

5.1 Triac Dimming

Triac (Triode for Alternating current) is a bidirectional thyristor device which can be used as a switch to conduct current in both positive and negative cycles of AC waveform. Triac dimmers fundamentally cuts the incoming AC mains Voltage to reduce the average value of the Output Voltage. Also known as Phase Control dimmers.
They are further categorised as Leading Edge and Trailing Edge Dimmers. The leading-Edge dimmer cuts down the part of AC waveform at the leading edge of AC waveform whereas the trailing dimmers cuts down the part of AC waveform at the trailing edge of AC waveform. These were first designed to control electronic low voltage transformers (ELV).

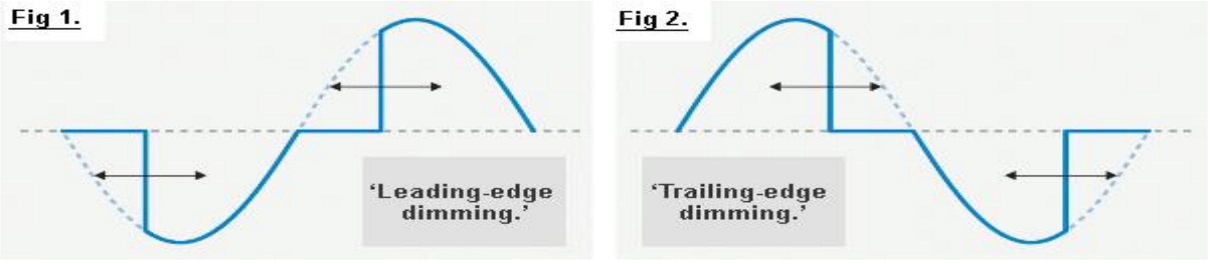


Fig.17

Though Triac dimmers have an advantage of simplest dimming method and easy on installation, it also leads to distorted input Voltage to LED drivers. Resulting in low power factor and higher harmonic distortion. LED drivers are reactive loads to the dimmer, which states that LED drivers will distort the incoming AC mains supply extremely by operating on nonlinear supply. They also present the zero-load condition at every AC waveform. This kind of zero-load condition make the dimmer operation to go wrong and creating flicker in light output. Except the controlled drivers which are designed to detect and react to the input supply in desired way. For an LED driver to react correctly, it is essential to add numerous vital blocks like sensors which can monitor the AC supply waveform before the power factor correction stage.

Fig. 18

In summary, Triac dimming is not ideal for dimming LED load and often results in limited dimming range, flickering, blinking and colour shifting of LEDs over the period. It's habitually used in retrofit applications where drawing additional control wiring is difficult and expensive.

5.2 0-10V / 1-10V / Analog Dimming

0-10V or Analog Dimming works on the small voltage (between 1-10V DC) control signal through extra pair of control wiring between dimmer and LED driver. These drivers dimmed from 100% (10V) to 10% (1V) to 0% (0V) means off.

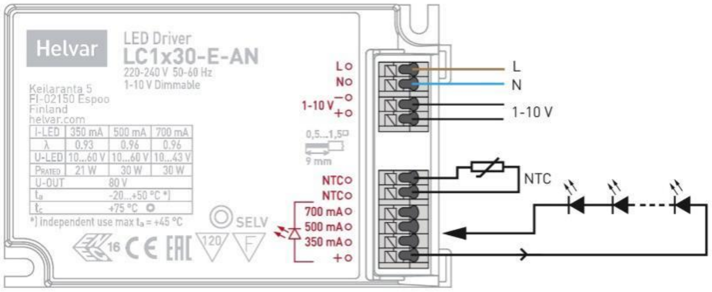


Fig. 19

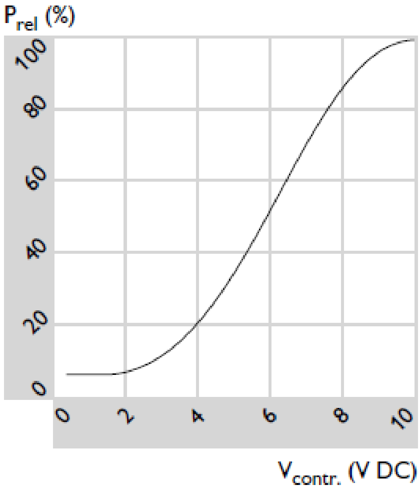


Fig. 20

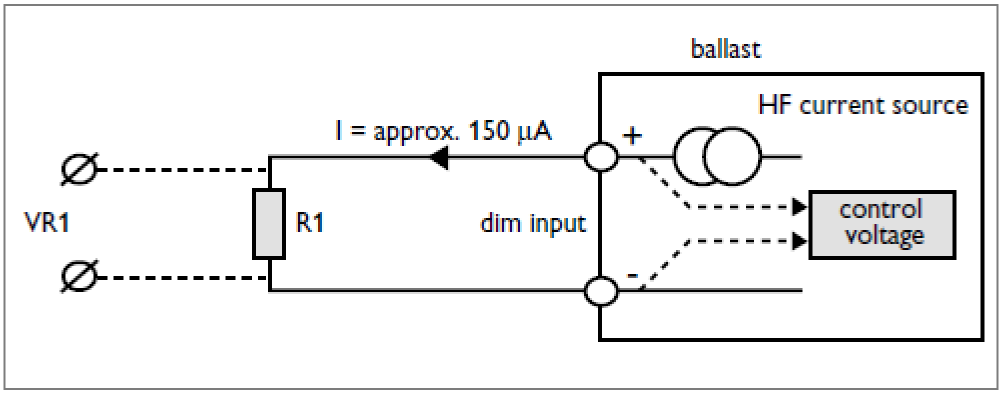


Fig. 21

These are further categorised into Current Sourcing and Current Sinking types. Sourcing current refers to the ability of the digital output port to supply current. Sinking current refers to the ability of the port to receive current. If the control input is not connected, the unit is in the 100 per cent light position.

If the control input is short-circuited the setting is at minimum lighting level. An external control voltage is not necessary. By inserting a potentiometer, continuous regulation can be achieved in a simple way. The control current that can be delivered by the driver is 0.15 mA.

The current source dimming is a front-end (user driven) method of lighting control intended for theatrical and entertainment applications.

Whereas the current sink method, a back-end protocol designed for architectural lighting fixtures. In this method, the LED driver is the current source for the DC signal and the dimmer is the point of reference. The driver associates the input voltage, which is adjusted by varying the voltage between 1 volt (minimum level signal) and 10 volts (maximum light), to a dimmed load. When these two control wires are open, the driver receives a 10V dimming signal and outputs 100% of the rated load. When the control wires are shorted together, the driver receives a 0V dimming signal and the output of the driver will be set to the minimum. If a level of 60% is set, the dimmer would sink the signal voltage to 6V. This method is also known as 1-10V dimming since 1 volt is the minimal level signal, and 0V turns the lamp off as the driver will drop in to sleep mode. Most 0-10V dimmable drivers dim from 100% to 10% apparent output.

Unlike phase control dimmers which cut power in the line voltage to the fixture, 0-10V dimming occurs in the driver and thus no heat is generated in the dimmer and transmitted across the wires. This attribute allows 0-10V dimmable LED drivers to control larger loads. The low voltage control wires are polarity sensitive. Long wire runs can cause a signal level drop, resulting in non-uniform light output from light fixtures which are operated by different drivers and controlled by the same control device.

Also adjusting the 0-10V signal with dimmers from different manufacturers will not necessarily achieve uniform dimming across different LED luminaires. What's worse is that poor compatibility among dimmers and drivers can present a new level of challenges.

5.3 Digital Dimming

A digital signal is connected to the led driver to provide dimming. The common form of digital dimming is PWM and DALI.

5.3.1 *PWM Dimming*

Pulse-width modulation (PWM) switches the LED current at a high frequency between 0 and the rated output current to adjust LED brightness. PWM dimming depends on the human eye's ability to assimilate the average amount of light in the pulses, also a digital dimming. The perceived brightness is approximately proportional to the duty cycle of the pulses (the ratio of the on-time and off-time). The continuous stream of pulses is modulated at a frequency high enough to be imperceptible to the human eye or even to high speed video cameras. Pulse-width modulation dimming can be used for LED arrays that run off either constant voltage (CV) drivers or constant current (CC) drivers.

A PWM driver will only operate the LEDs at the rated forward current level or zero. As such, the CCT of the LEDs is maintained throughout the dimming range. The consistent CCT simplifies the color mixing process. Since the LEDs are always on at the same current level, a very precise output level can be achieved. All these advantages make PWM dimming particularly viable for RGB full color tuning applications. PWM is also an energy efficient current modulation method because it periodically switches between a full-amplitude current and a zero current thus reducing the running time of the LEDs.

The primary disadvantage of PWM dimming is that high frequency switching can generate electromagnetic interference (EMI) and audible noise. In addition, PWM drivers cannot be remote mounted as the changes in capacitance and induction owing to increased transmission distance can end up in interference with high frequency control.

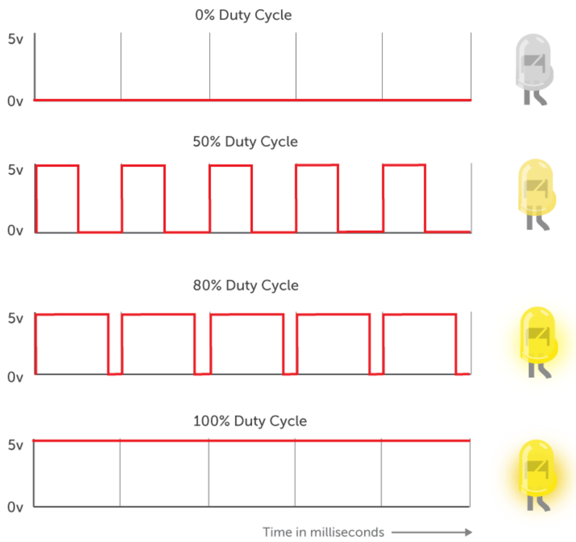


Fig. 22

5.3.2 *DALI Dimming*

DALI: **D**igital **A**ddressable **L**ighting **I**nterface. A New Protocol for Lighting Control for the Next Millennium

a) Digital Interface
b) Addressable (64 addresses, 16 Groups)
c) Preset or Scene Storage (16)
d) Logarithmic Dimming Curve (254 Steps)
e) Feedback eg. Led failure, Power etc.
f) The voltage across DALI wires is typically 16 V and it is polarity insensitive.
g) The DALI wires can be run alongside input main wires and the maximum current on a DALI line is limited to 250mA.

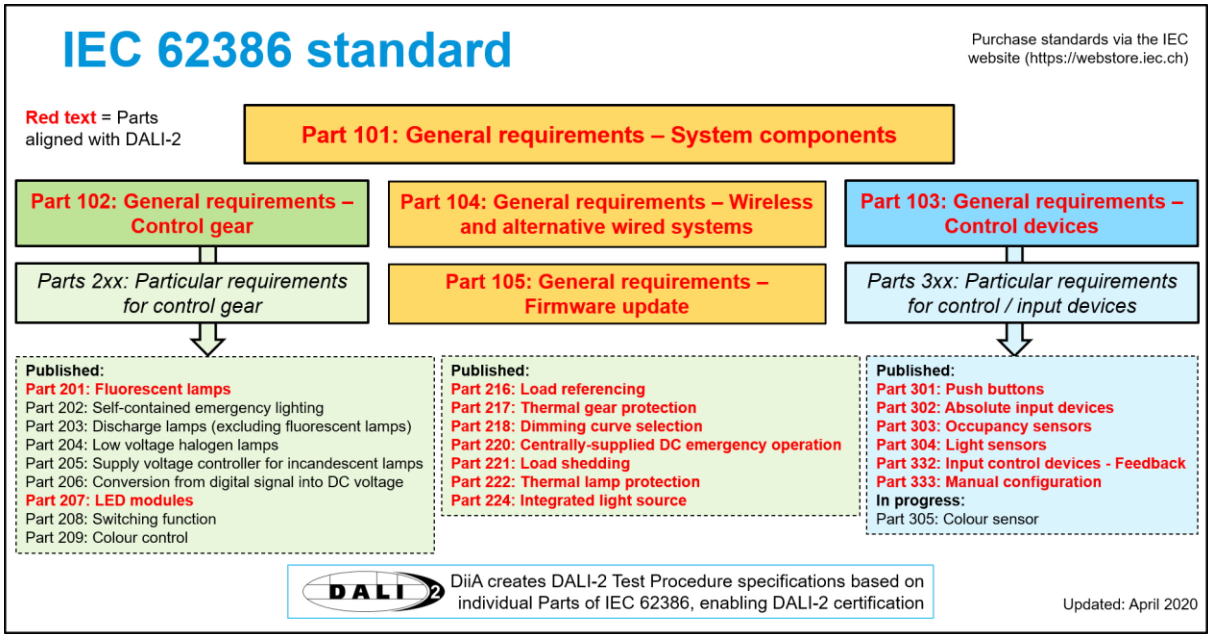
The voltage drop between two devices on a DALI network cannot be more than 2 V, resulting in a maximum length of 300 m between any two DALI components.

DALI was created to provide central control of light fixtures over a single pair of wires which operates at approximately 16VDC and carries a digital signal from a DALI controller to an LED driver. The other two wires provide a constant line voltage to the driver. This interface protocol for digital communication allows addressing, grouping, and dimming of up to 64 light fixtures and control devices. Its ability to communicate with the light fixtures individually, collectively or in groups via bi-directional data exchange provides great flexibility for light management. A DALI system can digitally assign occupancy sensors, photocells, time clocks, and other control devices to one or many fixtures without complicated wiring. DALI addresses the need for multilayer lighting control which requires light fixtures to respond to more than one controller and to be assigned to more than one control zones simultaneously.

The protocol uses logarithmic dimming with the curve matched to the sensitivity of the eye. DALI dimming technology uses 8-bit resolution for 254 individual steps, allowing users to obtain very precise output control with a dimming range of 0.1% to 100%.

DALI control lines have no polarity, which provides simplicity of installation. The DALI system uses a balanced pair of wires as the control bus and Manchester encoding for data-modulation. Therefore, the digital signal is immune to external interference, all light fixtures in a DALI lighting system can be uniformly dimmed.

The IEC 62386 standard was restructured in late 2014 for ease of use, and many improvements were made including the addition of new commands and features.



IEC 62386 standard

Purchase standards via the IEC website (https://webstore.iec.ch)

Red text = Parts aligned with DALI-2

Part 101: General requirements – System components

Part 102: General requirements – Control gear

Part 104: General requirements – Wireless and alternative wired systems

Part 103: General requirements – Control devices

Parts 2xx: Particular requirements for control gear

Part 105: General requirements – Firmware update

Parts 3xx: Particular requirements for control / input devices

Published:
Part 201: Fluorescent lamps
Part 202: Self-contained emergency lighting
Part 203: Discharge lamps (excluding fluorescent lamps)
Part 204: Low voltage halogen lamps
Part 205: Supply voltage controller for incandescent lamps
Part 206: Conversion from digital signal into DC voltage
Part 207: LED modules
Part 208: Switching function
Part 209: Colour control

Published:
Part 216: Load referencing
Part 217: Thermal gear protection
Part 218: Dimming curve selection
Part 220: Centrally-supplied DC emergency operation
Part 221: Load shedding
Part 222: Thermal lamp protection
Part 224: Integrated light source

Published:
Part 301: Push buttons
Part 302: Absolute input devices
Part 303: Occupancy sensors
Part 304: Light sensors
Part 332: Input control devices - Feedback
Part 333: Manual configuration
In progress:
Part 305: Colour sensor

DiiA creates DALI-2 Test Procedure specifications based on individual Parts of IEC 62386, enabling DALI-2 certification

Updated: April 2020

Fig. 23

With the latest innovations into DALI dimming protocol, DALI dimmable drivers are further categorising into DALI1, DALI 2, DALI 8 and D4i.

5.3.3 *DALI 1 DT6*

Fig. 24

DALI was originally developed to allow digital control, configuration and querying of fluorescent ballasts, replacing the simple, one-way, broadcast-like operation of 0/1-10V analog control. With DALI, the broadcast option is also available; in addition, with simple configuration, each DALI device can be assigned a separate address, allowing digital control of individual devices.

Fig. 25

The digital nature of DALI allows two-way communication between devices, so that a device can report a failure, or answer a query about its status or other information.

Mainly used for smooth and linear dimming of lights along with other benefits like maintenance/fault reporting, responding to PIR sensor, Day light harvesting, energy monitoring etc.

DALI version 1 certification process is carried out with self-assessment of driver with the help of testing software provided by Diia. The test reports doesn't need to be verified from Diia.

5.3.4 *DALI 2*

Fig. 26

DALI-2 refers to the latest version of the DALI protocol and developed to improve the original DALI and fill the gap.

For DALI-2, the IEC 62386 standard was restructured in late 2014 for ease of use, and many improvements were made including the addition of new commands and features.

One of the most significant changes in DALI-2 was the addition of control devices (including application controllers and input devices), which were not included at all in the original version of DALI.

The IEC 62386 standard is split into a number of Parts, and IEC continues to develop the standard with input from many DiiA members. Separately, DiiA also creates new specifications which are in turn transferred to IEC for inclusion in IEC 62386.

Key improvements of DALI-2 vs. DALI version-1 are as follows:

a) Improving the interoperability and reliability of the different devices in DALI systems;
b) Clarified bus signals and timing;
c) New requirements for bus power supplies;
d) 24-bit frames defined;
e) Improved failure reporting and fade time adjustment;
f) More detailed and comprehensive testing procedures;
g) Verification of the test results by DiiA;
h) Bringing in the standardisation of control devices too (sensors, control panels etc.), not just control gear (ballasts and drivers);
i) Allowing additional, separate 64 addresses for control devices, so total of 128 addresses per subnet;
j) Still maintaining the backward compatibility with DALI 1 devices.

DALI 2 certification steps are as follows:

a) Purchasing of certification credits;
b) Executing DALI-2 tests on the product to be certified;
c) When tests are passed, company submits the results to DiiA web tool;
d) Web tool verifies the results;
e) When accepted, company can use the DALI-2 logo on the product;
f) The certified product will be added to certified product database on Diia website.

5.3.5 *DALI DT8*

DALI Type 8, also known as DALI 209, is a DALI compatible device (device Type 8) which allows a user to change light color, color temperature and intensity to their preference, within the same fixture to achieve tunable white and RGB/W color changing.

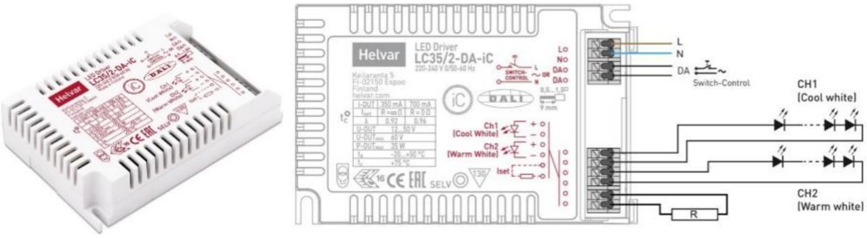


Fig. 27

DALI Type 8 uses a single DALI address to control 2 or more outputs on a DALI Type 8 driver, reducing the number of both DALI addresses and DALI drivers needed to provide this color changing capability, saving on cost and complexity.

For Tunable White solution, compared with normal DALI DT6 driver, DALI DT8 driver has lots of advantages.

a) For DT8, only need one DALI address to achieve Tunable White, whereas For DT6, need two DALI addresses to achieve Tunable White;
b) As a result, DALI address saving leads to lesser no of drivers and DALI controllers;
c) Need lesser time to install and commission the system;
d) Color mixing is uniform throughout the system and one can easily avoid the human errors by setting up the right color with the help of DALI commands;
e) In the end saving cost on overall LMS system and drivers.

Both RGB color mixing and color temperature tuning are now supported. Robust color control and automated dimming allow multiple light scenes to be called up for a room and dynamically presented in steps with variable durations.

5.3.6 *D4i*

Fig. 28

D4i brings standardization to intra-luminaire DALI, and extends the existing DALI-2 program by adding a specific set of new features. By specifying power-supply requirements and smart-data capabilities, D4i enables intelligent, connected, future-proofed LED luminaires.

Intra-luminaire DALI refers to a small DALI network inside an individual luminaire. D4i specifications ensure that power is available for control devices—such as sensors or wireless communication devices—that are attached to or integrated into the luminaire. Meanwhile, D4i drivers inside the luminaire are able to store and report a wide range of data in a standardized way.

The example below shows a two-node, outdoor-lighting application. Power available to both nodes, and the intra-luminaire DALI bus supports socketed systems. The intelligent luminaire has sensing capabilities and can report data stored in the LED driver to the external network via the DALI bus and the wireless link.

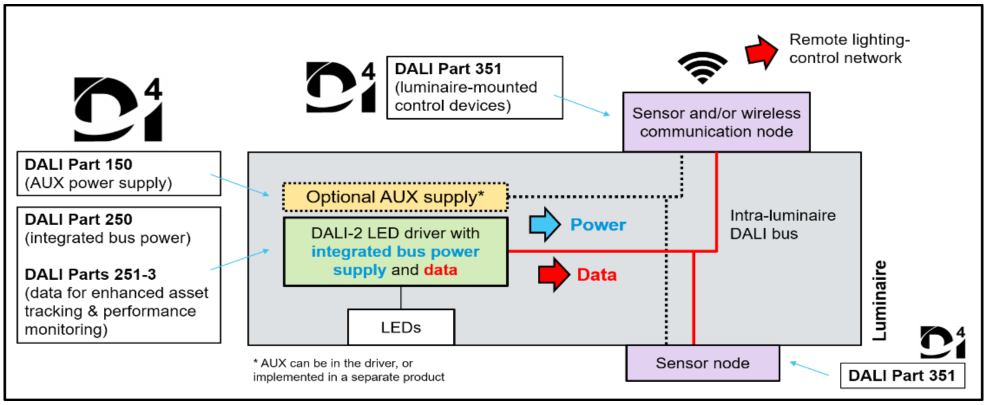


Fig. 29

5.4 DMX Dimming

DMX or DMX512, originally developed for entertainment and stage lighting applications, is now widely used to bring the drama and excitement of theatrical lighting into interior and exterior architectural spaces. DMX employs EIA-485 (RS-485) differential signalling at its two-wire physical layer. This variable-size, packet-based communication protocol has a transmission rate of 250 kBit/s. The unidirectional, channel-based protocol streams data continuously in a sequence of up to 512 data frames (slots) for up to 512 channels. Each DMX512 dimming channel controls one recipient and transmits data in 8 bits giving 256 steps of color depth. DMX is typically used to control RGB LEDs, which takes up three channels from the DMX512 stream to control one triplet. Data is transmitted over a cat5 or 3-core shielded cable which is polarity dependent.

Fig. 30

5.5 Switch Dimming

With switch DIM it is possible to create lighting systems that can be easily switched and dimmed at low cost. The key is simple but clever. It involves using standard mains voltage switches for lighting control. The different switching and dimming functions are performed depending on the operating status at the time and how long the switch is pressed. A short press on the switch switches the connected ballasts on or off; holding down the switch will fade the connected ballasts up or down.

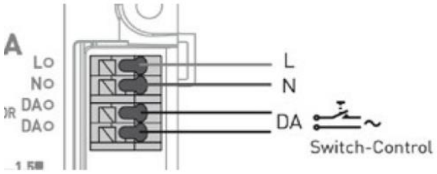


Fig. 31

Switch-Control operates by connecting the mains voltage to the DALI input terminals. Therefore, please ensure that all the components connected in this line are mains rated and protected according to all applicable safety requirements. The support of DALI operation is disabled for the time of Switch-Control operation and re-enabled with a mains reset. The maximum number of drivers per switch is 20. Ensure all drivers and other loads are connected to the same mains phase.

Table 1

Switch-Control active less than 50 ms	No operation. This is a protection against short interruptions and disturbances in the control cables.
Switch-Control active 100-350 ms	Short press (ON/OFF function); toggle operation between ON and OFF, Atswitch ON the light returns to the previous level before OFF;
Switch-Control active for Longer than 450 ms	Press and hold (Fade UP/DOWN); after switch ON the first dimming direction is always to dim down; if you press and hold from OFF the light goes to min level and starts fading up; the dimming direction is always changed when Switch-Control is released.

6 SETTING UP DRIVER OUTPUT AND VARIOUS OTHER PARAMETERS

6.1 Setting Driver Output

Nowadays, the output of the latest LED driver can be set with the help of Current Limiting resistor or Dip Switch selection on board.

6.1.1 The LED-Iset resistor/current setting values are adjusted according to the LED set specification. The resistor value for each required output current can thus be calculated from the formula R [Ω] = (5 [V] / I out [A]) * 1000. Below are the examples LED-Iset resistors.

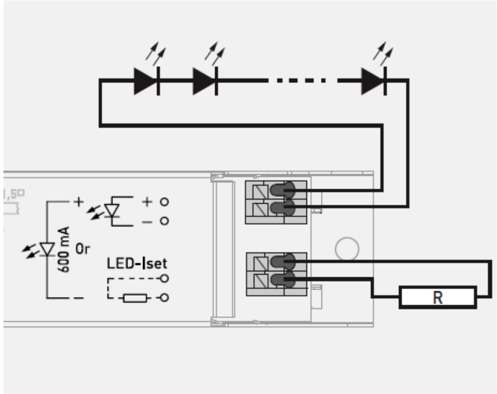


Fig. 32

LED-Iset resistor model	MAX	800 mA	750 mA	700 mA	650 mA	600 mA	550 mA	500 mA	450 mA	400 mA	350 mA	300 mA	No resistor
I_{out} (mA)	850	800	750	700	650	600	550	500	450	400	350	300	250
Order code	T90000	T90800	T90750	T90700	T90650	T90600	T90550	T90500	T90450	T90400	T90350	T90300	N/A
Resistance values (Ω)	0	6.2k	6.65k	7.15k	7.68k	8.25k	9.09k	10k	11k	12.4k	14.3k	16.5k	∞

Fig. 33

The current can be adjusted also with normal resistors by selecting suitable resistor value (formula R [Ω] = (5 [V] / I_out [A]) * 1000). Reference resistor values can be found below order code in the table above.

6.1.2 The current can also be set with dip-switches. With each combination of switch setup, a different output current value can be set. The maximum value can be reached with all switches set to "1" (pushed downwards, away from the connectors, see connections picture below).

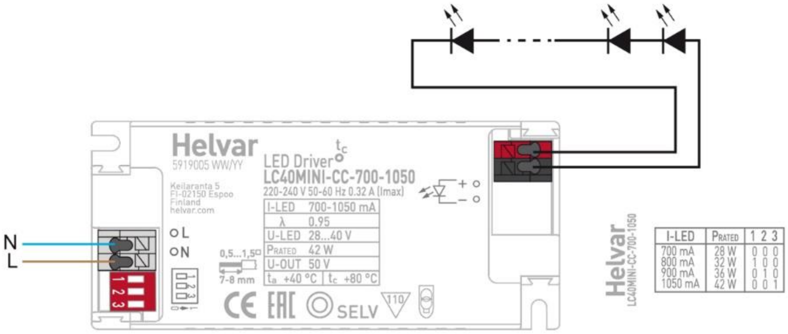


Fig. 34

6.2 Configuring Various DALI and Driver Parameters

Driver Configurator is configuration tool created for controlling the configurable parameters of the LED driver. Once device data is read, all functions supported by the connected driver will appear on the" Device Parameters" page. The configuration tool includes text fields where parameters can be modified: by typing into information fields or pressing buttons to select/enable/disable functionalities. An "Write" button in the "Device Parameters" tab uploads the modified parameters into the connected driver.

The program is used to control and program manually or automatically the connected drivers. Also driver address copying and physical driver identification features are available.

By” Create” button, user is able to create virtual configuration for specified driver without having connection to the LED driver, making the NFC operation easier as the driver is not mains powered in the configuration / programming operation.

The program is used for customizing the LED driver for a specific need. Following selection of configurable LED driver parameters are available:

a) Device identification and addressing;
b) Driver settings;
c) Automatic programming;
d) Command prompt commands for driver programming;
e) iC and DALI settings

- DALI settings allow to configure LED module parameters and driver parameters affecting the control of colour temperature in order to ensure a proper operation of colour and intensity control with Tunable White LED drivers
- Output power of driver/ballast shall rise monotonically as control voltage rises from VControlLo to VControlHi.
- For constant current drivers, maximum (or minimum) output power occurs at maximum (or minimum) output current, as measured per ANSI C82.16.
- The shape of the dimming input/output function of a driver or control unit shall be linear or logarithmic from VControlLo to VControlHi within the tolerances shown in Table 1. The manufacturer of the driver or control unit shall specify in the product literature whether the input/output function is linear or logarithmic.

  Note: This Standard offers two options for the shape of the dimming curve: linear or logarithmic. These options allow specifiers to optimize performance in a wide range of applications. Existing installations use either type of curve. To ensure compatibility, it is recommended to avoid mixing linear and logarithmic drivers/ballasts on the same control wires.

- The manufacturer shall specify in the product literature the minimum output power as a percentage of the maximum output power, e.g., 10%, 1%, 0.1%, or other numeric value.
- Standby mode (optional): Voltages below Voff can be used to place the LED driver into standby mode. See Figure 5. The manufacturer shall declare if standby mode is implemented.
- Depending on interface characteristics, several controllable driver/ballasts can be connected to one control unit, as shown in Figure
- The controllable driver/ballast shall be current sourcing.
- The driver/ballast shall not be damaged when the control input voltage V1,2is between −15 V and +15 V.

- The driver/ballast shall not produce control voltages that exceed the following:−15 V < V1,2 < +15 V.

- The driver/ballast control terminals shall be reverse polarity protected. In the case of reverse polarity, the driver/ballast shall operate with minimum output or shall not operate.

If the control signal is not connected, the driver/ballast shall provide the maximum value of output power.

- At a control signal between 0 V and 11 V, the driver/ballast output power shall be stable. Compliance shall be determined by the method of measurement in ANSI C82.16 and observation of the output voltage on an oscilloscope.

- The control unit shall be able to produce a minimum control signal, VCumin, in the range of 0.2 V to 1.0 V. The manufacturer shall specify in the product literature the minimum control signal that the control unit can produce. The tolerance of the minimum control signal shall be ±0.2 V.

- The control unit shall be able to produce a maximum control signal, VCUmax, of 10 V ±1.0 V.

6.3 Control Current Limits

The driver/ballast control current supplied to control unit(s) shall be between 10 µA and 2 mA, inclusive.

The minimum value of the control input current that a driver/ballast can source shall be declared by the manufacturer in the product literature.

The maximum value of the control current that a control unit can sink shall be declared by the manufacturer in the product literature.

The control unit shall allow the 0-10 V control wires to be driven to a lower DC voltage by any other control unit(s) on the same control wires without sustaining damage or generation of opposing electrical current greater than 100 µA. (*See* Fig 3)

6.4 Power on and Output Value Change Time

Upon application of power, the driver/ballast shall provide output power as determined by the control signal value. If standby mode is supported and V1, 2 is less than 0.8V, then the driver shall enter standby mode at application of power.

Time from power-on or standby (if standby mode is supported) to output power as determined by the control signal value shall be no greater than 1.5 seconds.

If a driver/ballast does not have a built-in fading function, the time to change from one output value to another when powered on and not in standby mode shall be no greater than 500 milliseconds.

If a driver/ballast has a built-in fading function, the manufacturer shall state the nominal time to change from one value to another. If the driver/ballast has a range of transition times, the manufacturer shall state the minimum and maximum values and the factory default time to change from minimum output to maximum output value.

6.5 Lead Wire Colours

When lead wires are supplied with the driver/ballast to serve as control terminals, the wire color shall be violet for the "+V1" designation, and the wire color shall be gray for the "−V2" designation.

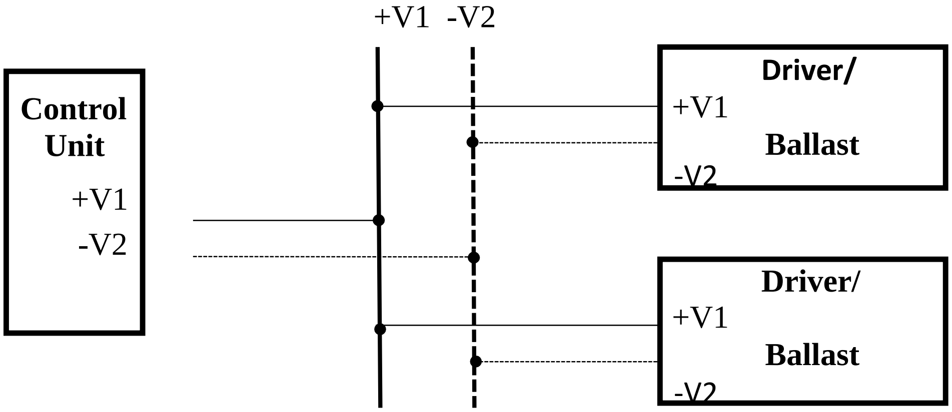


Fig. 35

6.6 Control Wire Requirements

The maximum voltage drop on the control wires shall be less than 0.3V.

Note: As a practical implication, the maximum wire length is given by the formula.

$$d = V/(2*R*n*I,$$

where:

d = is the distance of the wire run in ft (m)

V = 0.3 volts (i.e., maximum voltage drop)

R = is resistance per unit length of a single conductor of the wire in ohms/ft (ohms/m) n is the number of driver/ballasts on the circuit
I = is the maximum current sourced by each driver/ballast in amperes

In Class 2 installations and for the purposes of determining electrical interface requirements, wire electrical properties should be taken from UL 13, Table 20.1.

7 DALI TESTING

7.1 Set up example for wired DALI parameter settings as below:

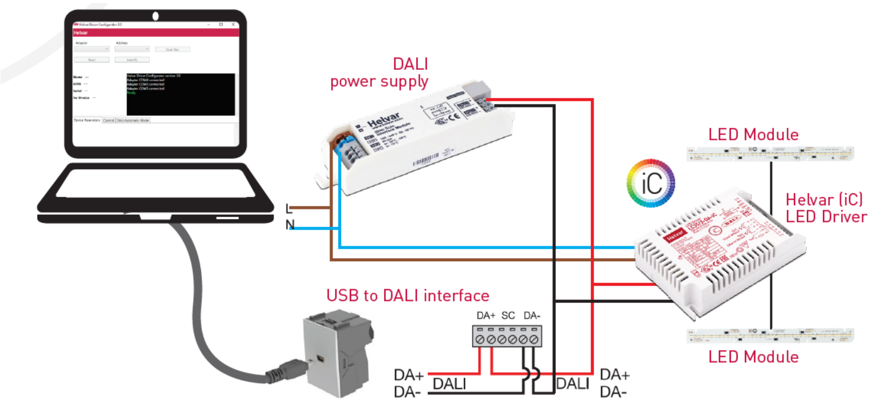


Fig. 36

The USB to DALI Interface unit is connected to the DALI power supply, and the driver under configuration with DALI bus. Please ensure correct polarity of the USB to DALI Interface and DALI power supply. LED driver and DALI bus connections are unipolar and require no special attention. The DALI power supply and the driver under configuration must also be provided with mains power.

7.2 Near-Field Communication (NFC) Connection

Photo: FEIG ELECTRONIC

Fig. 37

The NFC reader device drivers is install and the reader should be connected to the laptop before starting the software. For best wireless connectivity between driver and NFC reader, the NFC antenna (marked with logo) to be placed in middle of the black NFC contact area.
Following DALI driver settings are configurable through DALI configurator,

Table 2 General Settings

Power On Level (0-254)	Defines the light level where the lights switch ON after a mains break. Next to this text field is an indication of the selected level in percent value. Power On Last Level Enabled – by selecting this button the lights return on last DALI level used before the power break.
Write short address	When checked, also a short address is set during upload. This can be is useful if you want to copy the whole state of another device including the short address (read data from one device, select a new compatible device and upload with this option checked). If you want to change device address to some other value see "New short address" in "Control" tab. This feature is DALI specified and not possible via NFC.
System Failure Level (0-254)	Defines the DALI level where the lights go if the DALI line disappears. Next to this text field there is an indication of the selected level in percent value. System Failure Level disabled – Select this button if no operation is required after system failure.
Linear Dimming Curve	Select to use linear dimming curve. The DALI curve as default is linear for the human eye (logarithmic value scale).
Minimum Level (3 - 254 / 85 - 254)	Defines the minimum light level where the lights can be dimmed. In logarithmic scale the minimum value is 85 and in linear scale is 3, which both presents the minimum light level. The percent value of selected level is represented in the field below.
Maximum Level (3 - 254 / 85 - 254)	Defines the maximum light level where the lights can be dimmed. In both scales (logarithmic / linear) the maximum value is 254 (= 100% light level). The percent value of selected level is represented in the field below.

7.3 Device Independent Available Settings

In addition to general parameters, presented on previous page, several device dependant settings are configurable with Driver Configurator as well. Full list of the features are presented in Table 3:

Table 3 List of Features

Switch Control Enabled	Selecting this radio button enables the functionality if it is supported by the LED driver. Power On Last Level Enabled – selecting this lights return to the last DALI level used before the power break.
I_{set} by SW	Select this to set the current via software. This setting always overrides current setting via multipurpose Iset-terminal in the driver.

	The same driver terminal can then be utilized for other functions like the NTC operation.
Output current	Type in the driver output current in mA. If the value is outside of the LED driver output current range the driver will use the closest specified value. The drivers use the smallest output current as a default.
NTC Enabled	Select this feature to protect luminaire from critical high temperatures. The default NTC trigger value is specified in LED driver datasheet.
NTC value	Type in the NTC value corresponding to the trigger temperature. The value / resistance trigger point value correlation table
CLO Enabled	Select this to compensate against light depreciation of the light source. CLO Start level (%) – type in desired light level to maintain Constant Light Output CLO Life Time (x1000 h) – type in desired lifetime in thousand hours. This time describes when the output current needs to be on 100% level to maintain the selected Constant Light Output.
OEM customer data	Data input fields for customer specified GTIN and ID-number data.

8 CONTROL PARAMETERS

Driver operation can be tested in control section, where light level and colour temperature can be changed. Driver addressing and address removal are also possible.

Table 4 Light Level and Color Temperature

Light level	Real time control to set the light level of the device.
Active colour temperature	Real time control to set the colour temperature for Tunable White devices.
New short address	Select a new short address (1-64) for the device. The new short address is written using “Set” button.

9 TUNEABLE AND DALI PARAMETER SETTINGS

The driver must support multiple output channels, which are controlled individually. Two channels are used for tunable white, and up to four for RGBW (red, green, blue and white). DALI device type 8 can control these multiple channels using only one DALI address, allowing for more devices on each DALI subnet.

Note- that colour temperature calculations are made in Mired units to ensure the most accurate performance and the best result for tunable white solutions. Using Mired units corrects the non-linearity of colour temperature on Plancian Locus Curve. This conversion on LED driver calculations from mireds to Kelvins show rounding to actual Kelvin values displayed.

Table 5

Ch 1 (cool) Tc (K)	Defines colour temperature for Channel 1 cool white LED.
Ch 2 (warm) Tc (K)	Defines colour temperature for Channel 2 warm white LED.
Ch 1 (cool) TY (lm)	Defines lumen output for LED module(s) connected in Channel 1.
Ch 2 (cool) TY (lm)	Defines lumen output for LED module(s) connected in Channel 2.
Power On Colour (K)	Defines colour temperature where the lights turn ON after mains breakage. Power On Last Colour Enabled – by selecting this button the light will return to the last colour temperature used before mains breakage.
Power On Level (0-254)	Defines the light level where the lights switch ON after a mains break. Next to this text field is an indication of the selected level in percent value. Power On Last Level Enabled – by selecting this button the lights return on last DALI level used before the power break.
System Failure Colour (K)	Defines colour temperature where the lights go if the DALI line disappears. System Failure Colour Disabled – select this button if no operation is required after system failure.
System Failure Level (0-254)	Defines the DALI level where the lights go if the DALI line disappears. Next to this text field there is an indication of the selected level in percent value. System Failure Level Disabled – select this button if no operation is required after system failure.
Linear Dimming Curve / Minimum level / Maximum level	Same functionality as descibed in basic DALI functions on page 4. In Tunable White products, the physical minimum value is shown as well.

10 INDOOR AND OUTDOOR DRIVERS and THEIR APPLICATIONS GUIDELINE

10.1 Classifications

The electronic driver portfolio can be divided in a range dedicated for indoor application and the other range is specially developed for outdoor use. The major differences between indoor and outdoor applications are.

a) Risk due to salts, chlorides or other air contaminations (near sea, tunnels);
b) Risk of lightning strokes (high poles in open field);
c) Risk due to humidity/moisture in the driver;
d) Risk for strong bumps and/or vibrations (high poles, close to heavy traffic, bridges);
e) Risk due to strong mains distortions, voltage spikes, and surges.

And last but not least one other major difference exists between indoor and outdoor applications, being the customer expectation of the driver lifetime and failure rate. Compared to an office or shop application, customers have a much higher expectation of quality of lifetime and failure rate in an outdoor environment. Customers will be confronted that replacement of an outdoor driver could result in high to very high costs (closing tunnel/highway, sports lighting). Simple residential led driver used in commercial applications for continuous many burning hours also make the difference. er hour!).

Table 6 is the overview of requirements when using Indoor and Outdoor drivers:

Table 6

Sl No.		**Indoor Products**	**Outdoor Products***
(1)	(2)	(3)	(4)
i)	Air contaminations	No protection needed	Protection needed against exhaust gasses (chlorides) and salts
ii)	EMC-V surge	IEC 1000-4-5 Installation class 3*) 2kV L/N – Ground 1kV L-N	IEC 1000-4-5 Installation class 4*) 6-10 kV L/N – Ground (common mode) 4-8 kV L-N (differential mode)
iii)	Vibration levels	IEC 68-2-6-Fc Frequency range 10 - 150 Hz. Acceleration/amplitude 2G/0.15mm peak	IEC 68-2-6-Fc Frequency range 10 - 150 Hz. Acceleration/amplitude 5G/0.15mm peak
iv)	Lifetime	40k-50k hours@ 90% survivals	60k-100k hours@90% survivals
v)	Temperature range luminaire	Tamb 0 – 40 °C	Tambient -30 – 35 °C
vi)	ESD protection	No special requirements	LED module protection against ESD charging due to wind
vii)	Repair cost	Low	Typically very high per incident

10.2 Using Indoor Drivers In Outdoor Applications Guideline

In practice we see that for some less demanding outdoor applications such as bollards, decorative and architecture lighting successfully indoor drivers are used. Customers sometimes protects the electronics in the luminaires and accepts failures in case of surges because replace cost are relatively low.

Guideline of using different type of driver for different applications.

10.3 Constant Voltage Vs Constant Current

10.3.1 *CC -Constant Current Led driver*

A constant current LED driver maintains a steady output LED current at different LED voltages. This provides the optimum operation for LEDs to reach the possible long life.

10.3.2 *CV - Constant Voltage supply*

A constant voltage supply will regulate a certain output voltage. Not used for direct connecting LEDs.

11 LED DRIVER MARKING AND RATINGS

11.1 Permanent Marking

Drivers shall be permanently marked per the requirements of the applicable industry safety standards (e.g., IS15885). The model no of the product should be a part of Label and no stickering is allowed altering the current and voltage rating of driver

11.2 Rated Supply Voltage Designation Supply (Input) Ratings

The LED driver ratings and markings should include:

a) The maximum nominal input voltage;
b) The maximum input currents;
c) The maximum input powers;
d) The input frequency (e.g. 50 Hz).

Note: A LED driver with a dynamic input voltage range (e.g., 120 to 277V) should be marked with the input current at the minimum nominal input voltage and at the maximum nominal input voltage.Any other input current shall be in between these two extreme values.

Additional input information may be provided in the driver manufacturer catalogue and data sheets.

11.3 Output Regulation

Until such time as further marking requirements are specified in standard, the manufacturer in product literature or on the product itself.

11.4 Common Voltage Ratings (Nominal (Input or Supply) Voltage and Frequency)

The preferred design-centre supply-voltage ratings for drivers covered by this standard are 100-300VAC at 50Hz.

11.5 Led Load (Array, Module, or Package)

The rated load of a driver shall be specified as noted below.

a) Maximum output wattage of the driver;
b) For drivers that supply a constant voltage, output voltage in volts ac or dc on the product label;
c) In any collateral publications (instructions, specifications), the output voltage in VDC shall include a tolerance band specified as a percentage (e.g., 24 VDC ±5%);
d) For drivers that supply a constant current, output current shall be specified in amps on the product label;
e) In any collateral publications (instructions, specifications), the output current in amps shall include a tolerance band specified as a percentage (e.g., 5 amps ±5%);
f) For drivers designed to operate specific modules or arrays, those modules and/or arrays shall be specified on the label and/or in the install instructions.

Note: The output rating and the maximum output capability are not usually the same.

11.6 Led Driver Operating Temperatures

Drivers are designed to start and operate LED loads over a range of ambient temperatures. Due to variations of thermal transfer capabilities with fixture designs, the ambient temperature is not always an ideal way to specify product capability while the maximum T_c is a better measurement for application determination. The minimum ambient temperature and the maximum T_c temperature and location should be clearly marked on the product label or product specification documents. As a guideline recommendation is for tc marking on the driver housing.

12 EMI - ELECTROMAGNETIC INTERFERENCE

EMI/RFI. Because Led drivers operate at high frequency, they may produce electromagnetic interference (EMI) or radio frequency interference (RFI). RFI frequencies are a subset of EMI frequencies. EMI issues cover all possible operating frequencies while RFI is only concerned with radio and television frequencies. This interference could affect the operation of sensitive electrical equipment, such as radios, televisions or medical equipment.

12.1 Two types

12.1.1 *Conducted Emission*

Interference conducted via mains (terminal interference voltage). Poor filtering / no grounding results higher conducted emission. This pollutes mains supply.

12.1.2 *Radiated Interference*

Interference due to Electro Magnetic radiation. This affects other equipments.

12.2 Applicable Standards

a) CISPR 15 (for frequency range 9KHz to 30 MHz);
b) EN55022A (for frequency range > 30 MHz);
c) FCC Class A (for frequency range 450 KHz to 30 MHz).

13 EMC - EMISSION AND IMMUNITY REQUIREMENTS

To ensure proper operation and immunity to external electrical disturbances and minimize emissions, the following criteria shall be met.

13.1 Electromagnetic Interference Suppression

Drivers shall comply with government regulations for reference use CISPR15.

13.2 Line Transient (Surges)

Electronic drivers are susceptible to line transients; therefore, transient protection shall be included. The guidelines for this protection shall be as described in IEC 61000.

14 TLA - TEMPORAL LIGHT ARTIFACTS

Change in visual perception, induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a human observer in a specified environment.

14.1 Flicker

Perception of visual unsteadiness induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a human observer in a specified environment. *~0-80Hz.*

14.2 Stroboscopic Effects

Change in motion perception induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a non-static environment. *~80Hz-2kHz.*

14.3 Phantom Array Effects

Change in perceived shape or spatial positions of objects, induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a non-static observer in a static environment. *~80Hz-2kHz*

14.4 What is The Problem With TLA?

a) May cause eye strain or headaches, may impair visual or cognitive performance, Distracting,

b) May trigger medical conditions *(in severe cases)*

c) Interferes with optical equipment (cameras, bar code readers, etc.),

d) Could slow adoption of LED lighting due to perceived poor performance.

14.5 Why do LEDs flicker?

They faithfully reproduce light based on the amount of current flowing through them. Primarily driver is responsible for that. Right driver design can eliminate these effects.

14.6 Sources of TLA

a) Source voltage changes (noise)
b) Externally coupled noise sources
c) Dimmer phase angle instabilities (when dimming)
d) Driver instabilities
e) Driver (intended) operation

14.7 Current TLA/TLM Measures

14.7.1 *Simple*

Percent Flicker and Flicker Index

14.7.2 *Complex*

IECPST and SVM

14.8 Flicker Testing (PST)

IS 14700 (Part 4/Sec 15), IS 14700 (Part 3/Sec 3) : 2018 and IEC TR 61547 may be referred for Flicker testing.

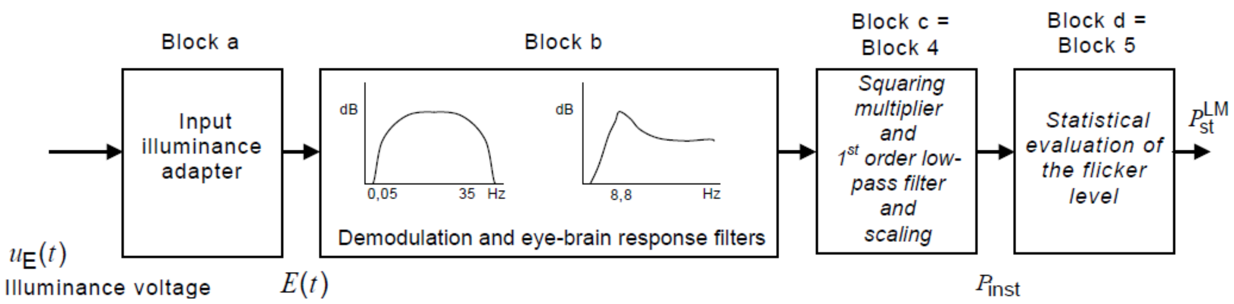


Fig. 38

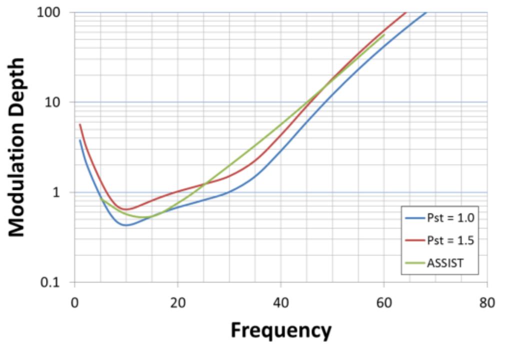


Fig. 39

14.9 Stroboscopic Visibility Measure (SVM)

a) Measures stroboscopic effects >50Hz;
b) Intended for indoor office-type environments;

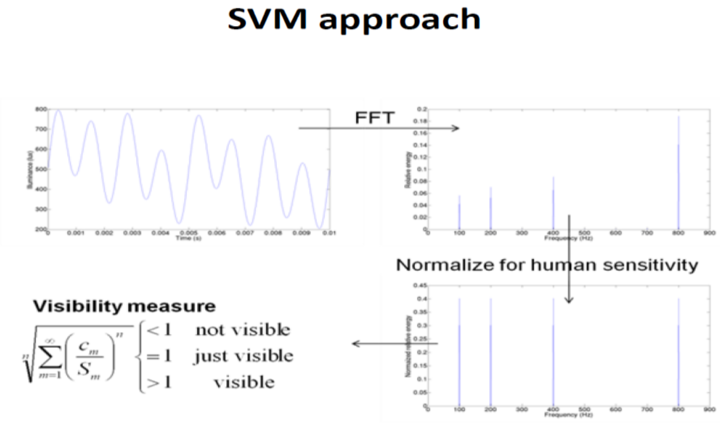


Fig. 40

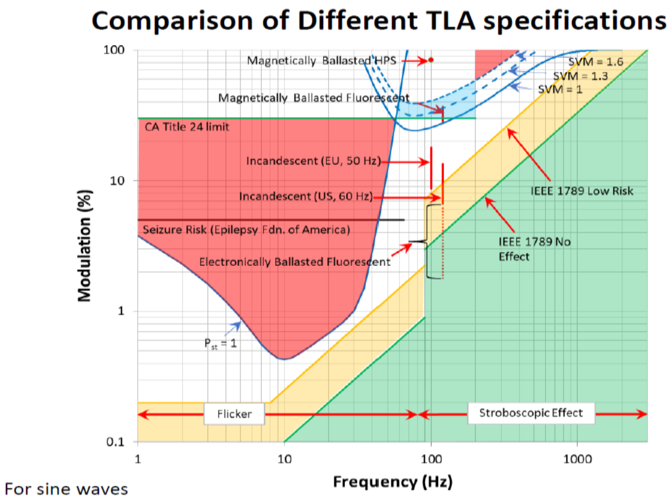
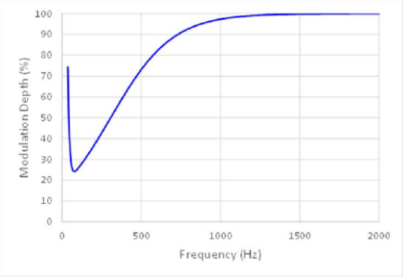


Fig. 41

c) Based on human perception trials
d) Accounts for frequency and waveshape

14.10 Human Eye Sensitivity Stroboscopic Only, Sine Wave



Plot of the Visibility Threshold

Tm(f) for the stroboscopic effect, expressed in terms of modulation depth, as a function of frequency. The curve is for a single sine wave modulation

Fig. 42

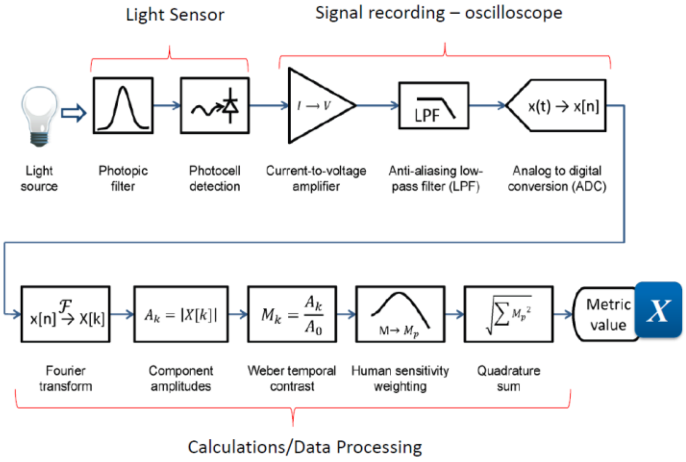


Fig. 43

14.11 Basic SVM Measurement

Refer Table 7.

Table 7

Sl No.	Product Application Area	P_{st}^{LM} limit	SVM limit
(1)	**(2)**	**(3)**	**(4)**
i)	Outdoor	≤ 1.0	None
ii)	Indoor	≤ 1.0	≤ 1.6

15 SAFETY REQUIREMENT

Drivers shall comply with IS 15885 or other safety standards as applicable, including but not limited to the following parameters:

a) Normal Temperature Operation Test;
b) Dielectric Withstand Test;
c) Leakage Current Test and Dielectric Voltage Withstand Test After Humidity Exposure;
d) Leakage Current Test;
e) Maximum Output Voltage Test;
f) Strain Relief Test;
g) Endurance Test on Overcurrent / Over temperature Devices;
h) Abnormal Tests (transformer burnout, reverse polarity, component breakdown, overload);
i) Dry, Damp, Wet Location Test (Humidity, Standing Water Test, Rain Test, etc.)

16 DRIVER PERFORMANCE GUIDELINE

16.1 General

The LED driver shall maintain the specified performance throughout its lifetime under the operating conditions specified. The driver should be tested per the requirements in IS 16103 (Part 1) and IS 16103 (Part 2)

Note: If a driver can operate over a wider range of voltages or currents than specified, this should be identified by the manufacturer.

16.2 Operating Conditions

For reliable operation, a driver for LEDs shall be designed to meet the operating parameters of Section 3 when tested at a temperature of 25 ±5°C.

16.3 LED Driver Input

A power line circuit having a maximum impedance as specified by IS 16103 shall be used to determine compliance with this section.

16.3.1 *Operating Supply Voltages*

When operated at any supply voltage between 90 percent and 110 percent of its rated supply voltage and at rated input frequency, a driver shall provide current and/or voltage regulation that equals or exceeds the values specified by the manufacturer.

16.3.2 *Input Current Harmonic Distortion*

The harmonic distribution of the input current shall comply with the requirements of IS 16103.

16.3.3 *Input Inrush Current*

There is a need to control inrush current transients caused by capacitor charging. Inrush currents shall be limited as specified in IS 16103.

16.3.4 *Input Current*

The LED driver input current, expressed in amps, shall be measured at the nominal input voltage of 120, 208, 277, 347, or 480 VAC, be connected to a branch circuit as described above in Clause 3.2, and have connected to the output the maximum load whether it be a LED array, module(s), or package(s).The LED driver input current for a dynamic range LED driver should be measured at the minimum nominal driver input voltage and at the maximum nominal driver input voltage, e.g., at 120 and 277 V for a LED driver rated for a 120 to 277 V range.

16.3.5 *Input Power*

The LED driver wattage, expressed in watts (W), shall be measured at the nominal driver input voltage and have connected to the output the maximum load whether it is LED array(s), module(s), or package(s). The LED driver input power for a dynamic range LED driver should be measured at the minimum nominal driver input voltage and at the maximum nominal driver input voltage, e.g., at 120 and 277 V for a LED driver rated for a 120 to 277 V range.

16.3.6 *Power Factor*

The LED driver power factor, expressed as a decimal never greater than 1, shall be measured at the nominal driver input voltage and have connected to the output the maximum load whether it be LED array(s), module(s), or package(s). The LED driver input power factor for a dynamic range LED driver should be measured at the minimum nominal driver input voltage and at the maximum nominal driver input voltage, e.g., at 120 and 277 V for a LED driver rated for a 120 to 277 V range.

16.4 Driver Output

16.4.1 *Constant Voltage Regulated Output*

When operated at its rated supply voltage and frequency, a driver shall deliver a voltage within ±10 percent of its nominal output voltage over the entire voltage controlled operating load range.

16.4.1.1 *Load regulation*

When operated at its rated supply voltage and frequency, a driver shall deliver a voltage within ±5 percent, or the value specified by the manufacturer, of its nominal output voltage over the entire operating load range.

16.4.1.2 *Line regulation*

When operated at its rated supply frequency and with any supply voltage within ±5 percent of the rated supply voltage, the driver shall deliver a voltage within ±5 percent, or the value specified by the manufacturer, of its nominal output voltage over its operating load range.

16.4.1.3 *Output voltage ripple*

For dc output drivers, the total voltage ripple due to reflected mains frequency and high frequency shall be limited to ±10 percent, or the value specified by the manufacturer, of the nominal output voltage. Note: Low frequency ripple should be minimized to reduce LED flicker.

16.4.2 *Constant Current Regulated Output*

When operated at its rated supply current and frequency, a driver shall deliver a current within ±10 percent, or the specified value by the manufacturer, of its nominal output current over the entire current controlled operating load range.

16.4.2.1 *Load regulation*

When operated at its rated supply voltage and frequency, a driver shall deliver a current within ±10 percent, or the specified value by the manufacturer, of its nominal output current over the operating load range.

16.4.2.2 *Output current ripple*

Total current ripple should be minimized to reduce LED flicker. NEMA is currently developing an understanding of flicker requirements.

16.5 Dimming Regulated Output

16.5.1 *Load Regulation*

When operated at its rated supply voltage and frequency, a driver shall deliver a voltage or current within ± 10 percent, or the specified value by the manufacturer, of its nominal output voltage or current over the entire operating load range.

16.5.2 *Line Regulation*

When operated at its rated supply frequency and with any supply voltage within ±10 percent of the rated supply voltage, a driver shall deliver a voltage or current within ±10 percent, or the specified value by the manufacturer, of its nominal output voltage or current over the operating LED load range.

17 LED DRIVER CHECK LIST CONSTRUCTED ON KEY CHARACTERISTICS

17.1 Accuracy

Accuracy is the closeness of the measurement to specific value. In terms of LED drivers, it is defined in percentage and the range is typically between +/- 2% to +/- 5%. For an example the LED driver with Output of 700 mA, 50V having an accuracy of +/- 5% should not deviate beyond the window of +5% and -5%. i.e. 735 mA-665 mA, 52.5V-47.5V. 5% accuracy is considered good enough in LED driver circuits. Higher accuracy results in more précised output.

17.2 Lifetime

An LED driver is configured to convert the AC line voltage into DC output as efficiently as possible, and any energy lost in the conversion process will be converted into heat. This means an LED driver with 90% efficiency requires an input power of 100W/0.9 = 111 W to drive a 100W load. Among the input power 11W is the power loss that escapes in the form of heat.

This places a high thermal stress on the LED driver circuit. When the driver is co-located within the luminaire housing, the thermal load from the LEDs will end up in additional increase in the driver temperature. In addition to utilizing components that are rated for high temperatures, the driver must be designed to pull heat away from thermally sensitive components. Excess heat build-up will cause reliability issues with components, including electrolytic capacitors which will dry out when exposed to heat.

Battery-like components called electrolytic capacitors are typically the cause of early failure in standard operating conditions. Electrolytic capacitors have a gel inside them that gradually evaporates over the lifespan of the driver. High temperatures quicken the evaporation of the gel and shorten the life of the capacitor, causing the driver, and hence your LED, to stop working unexpectedly.

Therefore, drivers with higher TC points have longer lifetimes. Drivers must be used at operating temperatures below the TC point (or they must at least contain long-life electrolytic capacitors) to ensure that the driver lifetime exceeds the lifetime of the LED.

The higher the temperature is, the faster the electrolyte inside vaporizes. Every 10°C reduction increases the life by a factor of 2, according to the Arrhenius Law. The temperature rise of the power supply can be derived from the power supply's efficiency curve and the surface area of the power supply.

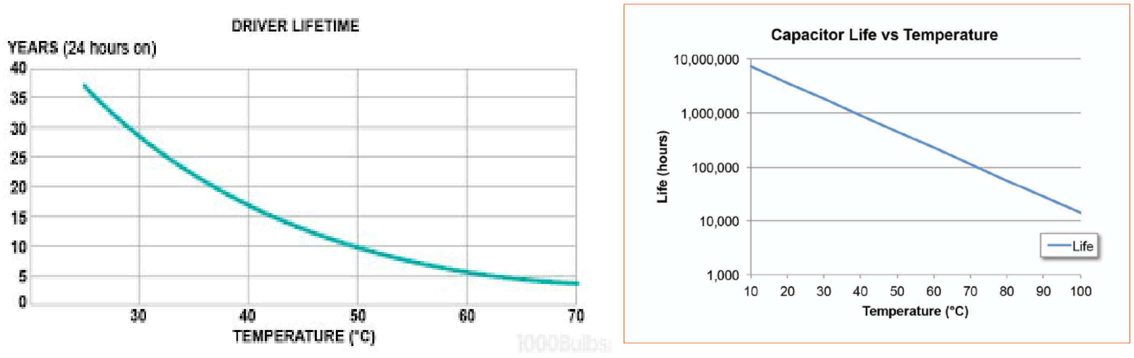


Fig. 44

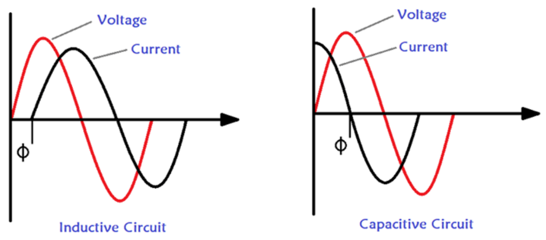
To facilitate heat dissipation, LED drivers for high wattage LED luminaires use aluminium enclosures which can come with high density fins and thermally conductive potting.

17.3 Power Factor

Power factor is the ratio of power utilized to power delivered and is expressed as a number between 0 and 1. A purely resistive loads has a power factor of 1 because It draws current exactly in phase with the line voltage. Nevertheless, the reactive elements such as capacitors and inductors of an LED driver draw an additional reactive current which is difficult to measure and therefore impossible for the utility companies to collect revenue from. Most importantly, this reactive power will cause the delivered power (apparent power) larger than the power required by the LED luminaire. This can cause the utility's infrastructure to operate above capacity and can incur damage potential if no measure is taken to protect the infrastructure from being overloaded by the additional reactive power.

The closer the PF is to 1, the more closely matched the current and voltage waveforms are. As the PF decreases, more power is wasted in the form of reactive power. In the commercial and industrial sectors, utilities will often surcharge end-users who operate with low-PF electrical equipment to compensate increased generation and transmission cost.

A power factor correction (PFC) circuit is typically used to minimize the reactive power and maximize the available power from the source and distribution cabling. PFC circuits, which include active and passive PFCs, shape and time-align the input current into a sinusoidal waveform that is in phase with the line voltage.



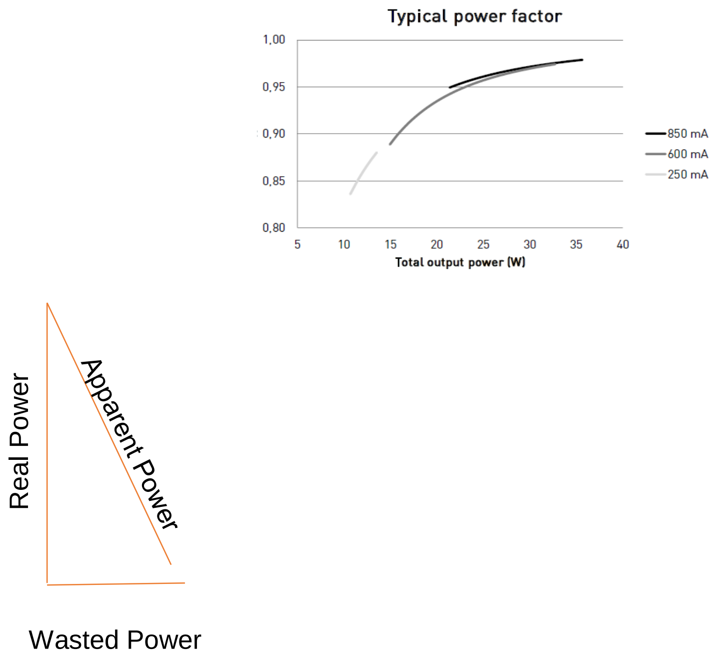


Fig. 45

17.4 THD - Total Harmonic Distortion

Total harmonic distortion (THD) is often brought up in the same breath with the issue of a low PF. THD is a measurement of distortion in the current waveform caused by non-linear electrical loads such as rectifier loads. Distorted current waveforms can reduce the PF and create harmonic distortion as well. Harmonic distortion also occurs when the load draws a current that does not resemble a true sinusoid.

THD is represented as a percentage. The lower the value, the better. High THD can cause issues within the power distribution equipment. So, it's important that LED drivers meet regulatory THD values (typically less than 20%) over the entire input voltage range. THD is suppressed by the power factor correction circuitry which must effectively shape the input current to ensure minimal energy at higher frequencies is generated.

Both PF and THD can be affected by dimming. Therefore, it is necessary to have PF and THD measured at full and dimmed outputs.

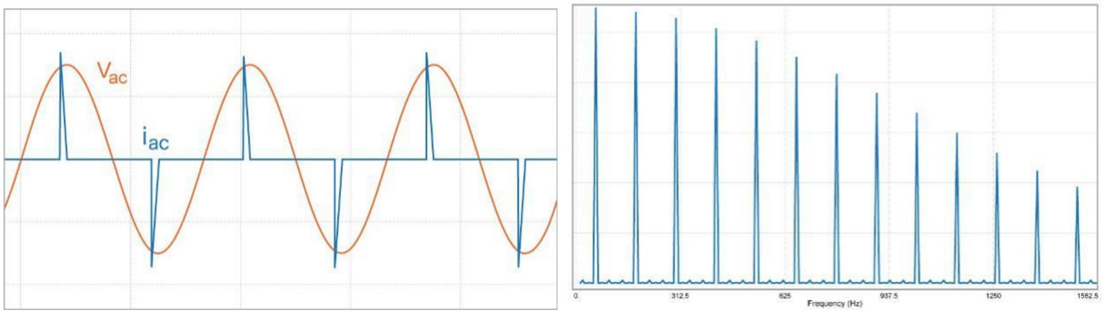


Fig.46 Voltage and current waveforms for a linear power supply

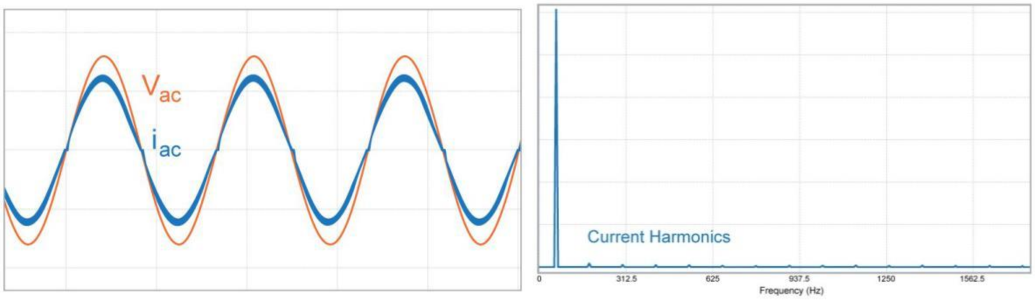


Fig.47 Harmonics of current flowing into a linear power supply

17.5 Efficiency

Efficiency is the ratio of total output power to input power, expressed in percent. This is normally specified at full load and nominal input voltage. Power supply efficiency is the amount of the actual power delivered to the components divided by the electrical power drawn from the mains supply socket.

$$\text{Efficiency} = \frac{\text{Useful power output}}{\text{Total power input}}$$

If a power supply with 50% efficiency is required to provide a 50W power to a load, it will draw 100 W from the wall. The other 50% gets wasted as heat and other losses. If a 90% efficient supply is used, it will draw 56W to supply the same load, meaning that it has fewer losses and uses less power from the grid to provide the same output power.

The power supplies do not have a constant efficiency; it varies with various factors such as the environmental and load conditions. The supplies achieve their maximum efficiency when operated at 50% of their load. In fact, the manufacturers guarantee the maximum efficiency only when the supply is run at 50% load.

This means buying a higher wattage supply which may be more expensive. However, it has some benefits such as reduced electricity bills; computer doesn't get very hot, hence reduced cooling and less fan noise. Power supplies tend to have higher efficiencies when connected to 230V as compared to the 110Volts ac.

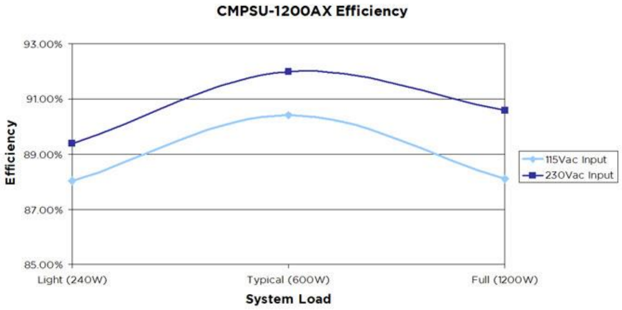


Fig. 48

17.5.1 *Losses in Power Supply Efficiency*

It is not possible to achieve 100 % power supply efficiency due to energy losses, but with proper design and component selection, high efficiencies of between 95 % and 97% are possible. Losses in power supplies occur due to passive and active components power losses. In SMPS, losses occur in the switching devices such as MOSFETS, and other junction-based semiconductors such as the diodes. Other losses occur in the capacitors and inductors especially when cheap, high resistance components are used.

17.5.2 *Passive Component Losses*

a) Resistor losses

b) Inductor losses due to Core and winding losses of inductors

c) Capacitor losses

17.5.3 *Active Component Losses*

MOSFET and diodes conduction and switching losses.

The MOSFETS and diodes are responsible for most of the power losses due to conduction and switching losses. The conduction losses occur due to the on-resistance of the MOSFET, and the forward voltage of the diode. Diodes have larger conduction losses which are proportional to the forward currents.

Other losses include the dynamic component losses due to the MOSFET and diode switching losses that occur during the transition between the ON and OFF states since some power must be consumed as the devices change their states.

Even though expensive, high efficiency drivers help save on electricity costs, they are also more reliable, less noisy and require less cooling. These often use higher quality and better characteristics components to produce better outputs with fewer ripples, less heat and better voltage regulation. These components selection includes the switching devices, heavy duty capacitors and chokes in addition to better soldering work. Further, the design of the circuit may also reduce power losses and improve the efficiency.

17.6 Ripple Factor

Flicker is amplitude modulation of the light output that can be induced by voltage fluctuations in AC mains, residual ripples in the output current provided to the LED load, or incompatible interaction between the dimming circuits and LED power supplies. Flicker can cause other temporal light artefacts (TLAs) which include stroboscopic effect (the misperception of motion) and phantom array (pattern appears when eyes move). TLAs come in both visible and invisible forms. Flicker that occurs at frequencies of 80 Hz and lower is directly visible, and invisible flicker is the temporal variations occurring at frequencies of 100 Hz or higher. The stroboscopic effect and phantom array will typically occur within a frequency range of between 80 Hz and 2 kHz, their visibility varies in populations. While invisible TLAs is not perceptible to the human eye they can still have several negative consequences.

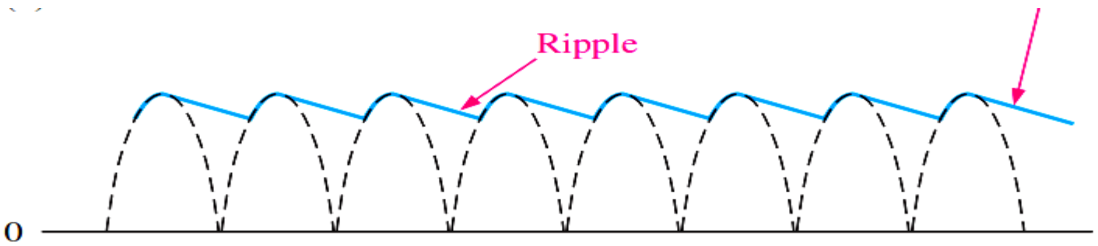


Fig. 49

Flicker and other TLAs are undesired temporal patterns of light output that can cause eye strain, blurred vision, visual discomfort, reduced visual performance and, in some cases, even migraines and photosensitive epileptic seizures. Therefore, they're one of the key considerations in light quality assessment. The intended use of artificial lighting plays a role. Different lighting scenarios may tolerate different level of temporal light artifacts. TLAs may be less of a concern for roadway, parking lot, and outdoor architectural lighting, or other applications where the duration of exposure to artificial light is limited.

Artificial light with a high percentage of flicker should not use for both ambient lighting and task lighting in homes, offices, classrooms, hotels, laboratories and industrial spaces. Flicker-free lighting is not only critical for visual tasks that demand precise positioning of the eyes and environments where susceptible populations spend considerable time, it's high desired for HDTV broadcasting, digital photography and slow-motion recording in studios, stadiums and gymnasiums. Video cameras can pick up TLAs the way like the human eye detects these effects.

The key to mitigating flicker lies in the LED driver which is designed to rectify commercial AC power into DC power and filter out any undesirable current ripple. Sufficiently large ripples, which typically occurs at twice the frequency of the AC mains voltage, in the DC current provided to the LED load result in flicker and other visual anomalies at a frequency of 100/120 Hz. Thus, the allowed level of ripple current in the LEDs, such as ≤2% ripple, must be defined in LED drivers for various applications where flicker matters.

The ripples may be smoothed out by using a filter capacitor. One of the major challenges in driver design is to filter out ripples and harmonics without using bulky, short-lived high voltage electrolytic capacitor on primary side. AC LED engines are inherently susceptible to the flicker phenomenon because the LEDs in fact run from what is essentially the intermediary DC voltage that would be in an SMPS-based LED lighting system. Rapid alteration in polarity gives rise to a flicker in the intensity at a frequency twice the AC sinusoidal frequency. Despite the simplicity in circuit design, additional circuitry is required to effectively reduce the progressive variation in the power supply.

Standards for limiting flicker for different applications are yet to be established. Two metrics were established by IES to quantify flicker. Percent flicker measures the relative change in the light modulation (the depth of modulation). Flicker index is a metric that characterizes the intensity variation over the entire periodic waveform (or duty cycle, for square waveforms). Percent flicker is better known to general consumers. In general, 10 percent flicker or less at 120 Hz or 8 percent flicker or less at 100 Hz is tolerable for most people except for the at-risk populations, 4 percent flicker or less at 120 Hz or 3 percent flicker or less at 100 Hz is considered safe for all populations and highly desired in visually intensive applications.

Unfortunately, many LED lamps and luminaires currently supplied on the market have a high flicker percentage. AC LED lights come with flicker typically higher than 30 percent at 120 Hz.

17.7 Surge Protection

Depending on the driver topology, circuit design and application environments, LED drivers can run up against load irregularities and abnormal operating conditions such as overcurrent, overvoltage, undervoltage, short circuit, open circuit, improper polarity, loss of neutral, and overheating, etc. Therefore, LED drivers should incorporate protection mechanisms in order to address these challenges.

The output voltage of some constant current drivers, especially switching boost converters, can rise too much above the nominal drive voltage due to load disconnection or excessive load resistance. Open circuit protection or output overvoltage protection (OOVP) provides a shutdown mechanism which uses a Zener diode to give feedback and conduct the output current to ground when the output voltage exceeds a certain limit. A more preferred method of open circuit protection is to utilize an active voltage feedback scheme to shut down the supply when the overvoltage trip point is reached.

Input overvoltage protection (IOVP) is designed to relieve the driving circuit from overvoltage stress because of switching operations/load change on the power grid, lightning strikes nearby, lightning strikes directly on the lighting system, or electrostatic discharge. In AC line applications, slight but sustained overvoltage can cause high currents (energy impulses) in the LED driver and LEDs, which may lead to failure of the LED driver and control interfaces, and the premature aging of the LEDs. A metal oxide varistor (MOV) or transient voltage suppressor (TVS) can be placed across the input to absorb energy by clamping the voltage. A plastic film capacitor, which is typically connected across the AC line to reduce EMI emissions, also helps absorb some of the energy in surge pulses.

LED drivers usually come with a limited level of surge protection from the built-in overvoltage protection circuits. In some applications such as street lighting, additional surge protection devices capable of surviving multiple surges or strikes should be added to the driver to protect downstream components from high surges. The SPD should be rated reduce or discharge high pulse energy of a minimum 10 kV and 10 kA, as per ANSI C136.2.

A short circuit at the load of a linear power supply can lead to overheating but makes no difference to the current supplied to each LED because the current limiting circuits provide automatic short circuit protection. However, in a switching buck regulator, a short circuit will lead to a failure of an LED or the entire module depending on the circuit design. The failure of a single LED usually has minimal impact on the total light output. The change in voltage can be balanced out using a self-adjusting current sharing circuit which still distributes the current equally. On the other side, a short circuit at the load of an LED string can significantly affect the total light output. The failure detection mechanism of short circuit protection can be implemented by monitoring the duty cycle. A short circuit typically results in a very short duty cycle.

Over temperature protection for LED systems include Module Temperature Protection (MTP) and Driver Temperature Limit (DTL). DTC uses an NTC (negative temperature coefficient) resistor to cut back output current when the maximum driver case point temperature in the application exceeds a predefined limit. MTC monitors the temperature of the LED module and is interfaced with the driver which automatically reduce the current to the LEDs when a threshold temperature is detected by the MTC. DTL can also be used as alternative to MTP if the driver TC point and LED module temperature can be correlated.

17.8 EMI and EMC

Electromagnetic interference (EMI), also referred to as radio frequency interference (RFI), affects other electrical circuit because of either electromagnetic conduction or electromagnetic radiation emitted by electronics such as those in LED drivers, CB radios and cell phones.

Any LED driver connected to AC mains supply has to meet the radiated emissions standards such as defined in IEC 61000-6-3. In an LED driving circuit, MOSFET switching is usually the main source of EMI. A PCB layout with paths for the switching currents kept short and compact is also important to limit EMI. In some applications an input filter is required to reduce high frequency harmonics and the design of this circuit is critical to maintain a low EMI. The ground plane on the circuit board must remain continuous to avoid creating a current loop that causes high levels of EMI to be emitted. A metal screen may be mounted over the switching area to provide an enclosure that stops EMI radiation.

17.9 Safety Considerations

Safety should always remain the number one priority when evaluating a driver and the lighting system it operates. A line-powered LED driver with dielectric isolation, e.g., 1500 V RMS (50 or 60 Hz), from input to output is highly desired. The input/output circuit isolation can only be accomplished with a transformer which has primary and secondary windings with good galvanic isolation. The output voltage must be kept below the 60 VDC safety extra low voltage (SELV) limit as per IEC 61140. However, there's an increasing number of LED lighting products which implement a non-isolated topology for the purpose of cutting cost. The risk of electric shock is a serious concern in LED products driven by low cost linear regulators. These circuits offer no isolation between the input and output circuits, and the electrical insulation of the lighting systems may have not been adequately tested.

The issues of creepage and clearance distances must be considered for AC powered products. The creepage distance between primary and secondary circuits must meet the spacing requirements otherwise electrocution or fire can occur. Clearance, which is defined as the shortest distance between two conductive parts, must be factored in to prevent arcing between electrodes caused by the ionization of air. As the sizes of electronic circuits continue to shrink, a good PCB design is essential for a driver circuit to not only reduce EMI emissions, but also reduces creepage and clearance problems.

All electrically conductive and touchable parts of a line-powered Protection Class I LED driver must be connected to earth. LED drivers designed to operate LED lighting systems for residential and commercial applications are typically listed as Class II. There's no enclosure grounding for class II LED drivers, but all the conductor inside a class II drivers must be dual or reinforced insulated to ensure good insulation between the mains power circuit and the output side or the metal casing of the driver.

17.10 Thermal Consideration

An LED driver is configured to convert the AC line voltage into DC output as efficiently as possible, and any energy lost in the conversion process will be converted into heat. This means an LED driver with 90% efficiency requires an input power of 100W/0.9 = 111 W to drive a 100W load. Among the input power 11W is the power loss that escapes in the form of heat.

This places a high thermal stress on the LED driver circuit. When the driver is co-located within the luminaire housing, the thermal load from the LEDs will end up in additional increase in the driver temperature. In addition to utilizing components that are rated for high temperatures, the driver must be designed to pull heat away from thermally sensitive components.
Excess heat build-up will cause reliability issues with components, including electrolytic capacitors which will dry out when exposed to heat. Therefore, the temperature at which an LED driver is running is fundamentally important in defining its lifetime. To facilitate heat dissipation, LED drivers for high wattage LED luminaires use aluminium enclosures which can come with high density fins and thermally conductive potting.

17.11 Ingress Protection

LED drivers for roadway, street, exterior and landscape lighting applications must be sealed to protect against ingress of dust, moisture, water and other objects that may pass through into the products. A high degree of ingress protection (IP) for LED drivers is critical for indoor applications such as carwashes, cleanrooms, bottling and canning plants, food processing facilities, pharmaceutical plants or any industrial application requiring exposure to daily high-pressure wash downs. Self-contained LED drivers for wet locations are usually potted in silicone to enhance enclosure integrity while also facilitating electrical insulation and thermal management. These drivers typically come with IP65, IP66 or IP67 level ingress protection.

17.12 Location Impact

LED drivers can be remote mounted or co-located within lamp or luminaire housings.
In co-located, non-DOB systems, the driver must be thermally isolated from LEDs which generate a huge amount of heat. Driver maintenance should be taken into consideration when designing a luminaire housing.

In remote-mounted systems, PWM drivers can experience performance losses over a long distance. As such, CCR (Constant current reduction) is the preferred dimming technique for remote-mounted systems.

18 THE DIGITAL TRANSFORMATION

18.1 Connected Products

Since the early 70's ever more products went through a digital transformation.
Products integrated CPU's and moved part of their existing and a lot of new functionality to software.

The integration of network functionality (IoT) allowed products to connect to each other, to applications on PC's and mobile devices and to the internet/back-end.

The law of Moore has consistently driven down the cost price of CPU's and communication bandwidth, allowing smaller products to be "digitized".

Fig. 50

The Digital Transformation outlook for Connected Lighting going to change the lighting market in very near future in all applications be it offices, home, retail, outdoor lighting etc. will become connected. Energy efficiency, personal control and data collection are the first functionality drivers. Although we are now started watching proprietary and open protocol solutions and islands of automation appear in the market today.