

LED Lighting

LED Lighting Basics



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Contents

- Why Led?
- Common LED lighting terms
 - Efficiency
 - Efficacy
 - Power factor
- Frequently encountered electrical terms
- LED configuration
- Isolated/Non-isolated
- Dimming
- TRAIC in lighting dimmers
- TI LED driver summary

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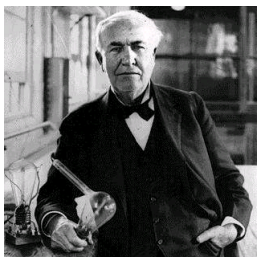
Why LED?



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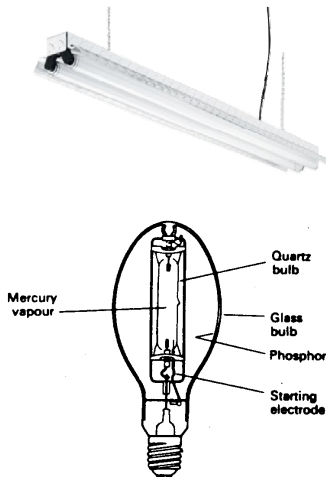
Incandescent Lamp



- First, we had the incandescent bulb (optimized, but not invented by, Mr. Edison):
 - Instant on and off
 - Near perfect color rendering
 - Easy to dim
 - Cheap to manufacture
- But, it had two “minor” issues:
 - It only lasts about 2,000 hours
 - It is horribly inefficient: only ~8% of the energy comes out as visible light



Discharge Lamp



- Next, we had low and high intensity discharge lamps, like fluorescent and high pressure sodium, respectively:
 - Lasted much longer
 - Much more efficient – 300-400% as efficient as incandescent
- But, they too have some issues:
 - Contain mercury, a neurotoxin
 - Can't be turned on and off quickly
 - Difficult and costly to dim
 - Color rendering ranges from very poor to acceptable



Solid State Lamp

- It turned out, it was more efficient and cost effective to install discharge lamps and leave them on all night than to modulate incandescent and replace them all every 6 months!
- But... what if we had the best of all worlds?

Power Conversion for "White" Light Sources

	Incandescent [†] (60W)	Fluorescent [†] (Typical linear CW)	Metal Halide [‡]	LED [§]
Visible Light	7.5%	21%	27%	15-25% Increasing rapidly
IR	73.3%	37%	17%	~ 0%
UV	0%	0%	19%	0%
Total Radiant Energy	80.8%	58%	63%	10-15%
Heat (Conduction + Convection)	19.2%	42%	37%	75-85%
Total	100%	100%	100%	100%

[†] IESNA Handbook [‡] Osram Sylvania

[§] Varies depending on LED efficacy. This range represents best currently available technology in color temperatures from warm to cool. DOE's SSL Multi-Year Program Plan (Mar 2006) calls for increasing extraction efficiency to more than 50% by 2012.



Common Lighting Terms

- Key Driver Attributes
 - Dimming
 - Analog Dimming, PWM Dimming
 - Efficiency
 - Total Harmonic Distortion (THD) & Power Factor Correction (PFC)
 - LED Current
 - Ripple
 - Reliability & Lifetime

- General Lighting & System Terms
 - Light Output Terms
 - Luminous Flux (Lumens)
 - Lux
 - Candela
 - Light Effects
 - Stroboscopic Effect
 - LED Flicker
 - Input and Output Voltage



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Key Driver Attributes

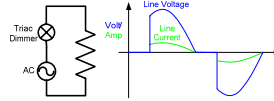
<p>Dimming Interfaces</p> <p>These are the different types of dimming devices that the driver is expected to work with.</p> <p>Most common interfaces are leading-edge (TRIAC) and trailing-edge (IGBT) dimmers and 0-10V</p>	<p>Efficiency/Efficacy</p> <p>Efficiency is the measurement of how good the power supply converts input power to output power and is measured in %</p> <p>Efficacy is the measurement of how good the luminaire is at converting electrical power to light and is measured in lm/w</p>	<p>PFC / THD</p> <p>Power Factor of an AC electric power system is defined as the ratio of the real power flowing to the load over the apparent power in the circuit</p> <p>Total Harmonic Distortion is the amount of harmonics that the driver creates and pushes back on to the AC line.</p> <p>Good PFC does not always mean good THD</p>	<p>LED Current</p> <p>LED Ripple is the amount of ripple current present on the output of the LEDs. This can cause flickering and is very common in single-stage PFC controller and typically needs large output capacitor to filter out the ripple</p> <p>Analog Dimming is an overall change to the output current seen by the LEDs</p> <p>PWM Dimming is a pulsing of the LED current at a given duty cycle at a frequency fast enough to make the LEDs appear dimmed.</p>	<p>Reliability/Lifetime</p> <p>Reliability is frequently luminaires are expected to fail during their operational life</p> <p>Lifetime describes how long luminaires can be expected to operate on average</p>



Review of Dimmer Concepts

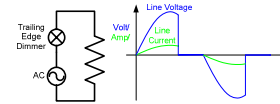
- **Leading Edge Dimmers**

- Otherwise known as TRIAC dimmer
- >70% of current dimmers are leading edge
- Holding current required for EU or US



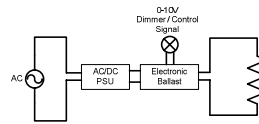
- **Trailing Edge Dimmers**

- Mainly used in newer infrastructure
- Does not impose holding current requirements
- Needs some minimum impedance for dimmer to function properly.



- **0-10V Dimming**

- Typically used for commercial applications
- One of the earliest and simplest electronic lighting control signaling systems
- Requires additional wiring



Review of Efficiency

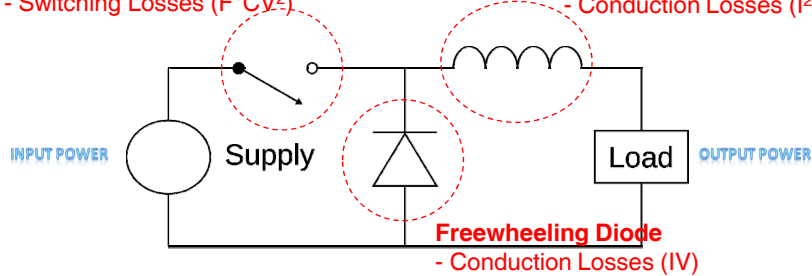
$$\text{EFFICIENCY} = \frac{\text{OUTPUT POWER}}{\text{INPUT POWER}}$$

Power FET

- Conduction Losses (I^2R)
- Switching Losses ($F \cdot CV^2$)

Inductor

- Conduction Losses (I^2R)



Simple BUCK Regulator ($V_{OUT} < V_{IN}$)

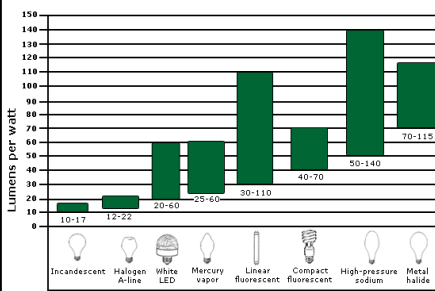


Lighting Efficiency

- The simple answer: Light, only when we need it, only where we need it, and only how much we need, not more.
- Overall efficacy has many elements:
 - Source efficacy
 - Power supply efficiency
 - Fixture efficacy
 - Light distribution efficiency
 - Light provided vs. light needed efficiency



Source Efficacy

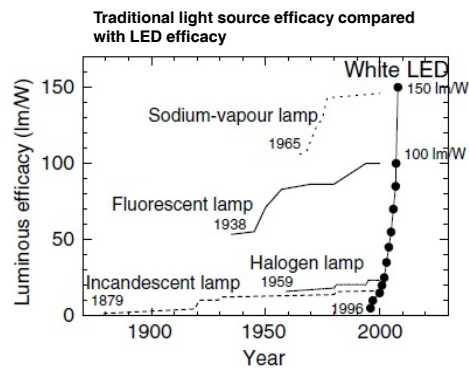


Traditional light source efficacy

Journal of Physics D: Applied Physics - White light emitting diodes with super-high luminous efficacy

Year	2009	2010	2012	2015	2020
LED Efficacy (lm/W)	113	134	173	215	243

Source: US Department of Energy, Solid-State Lighting Research and Development: Multi-Year Program Plan, March 2010.



Review of Power Factor

- **Power Factor** is the Ratio of Real Power (Watts) to Apparent Power (RMS Volt-Ampere product)

$$PF = \frac{\text{Real Power (W)}}{\text{Apparent Power (VA)}}$$

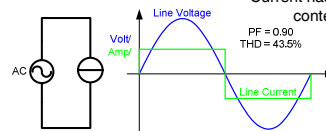
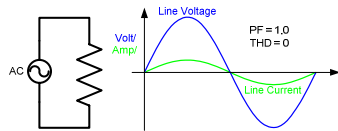
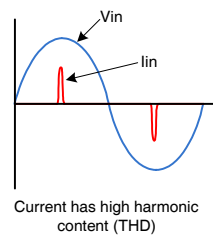
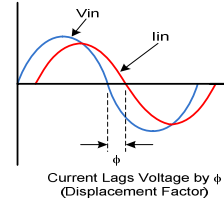
- **Power Factor** has two components –

- Displacement Factor (DispF) $DispF = \cos \phi$

- Distortion Factor (DF) $DF = \frac{I_1}{I_{rms}} = \frac{1}{\sqrt{1+THD^2}}$

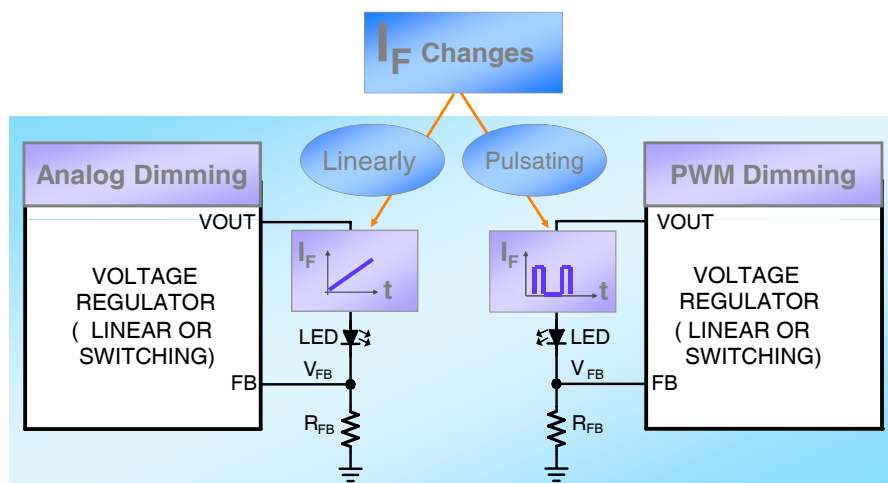
- **Power Factor** PF is the product of DF and DispF

$$PF = \frac{1}{\sqrt{1+THD^2}} \cdot \cos \phi$$



TEXAS INSTRUMENTS

PWM vs. Analog Dimming (1)



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TEXAS INSTRUMENTS

PWM vs. Analog Dimming (2)

- Analog dimming consists of changing the constant current through the LED by adjusting the sense voltage.
 - Quiet, does not generate additional noise in the system.
 - The dominant wavelength varies with LED current however, so the color will change using this method.
- PWM dimming consists of setting a desired LED current and turning the LED on and off at speeds faster than the human eye can detect.
 - Noisier. The input supply must be filtered properly to accommodate the high input current transients.
 - The dominant wavelength does not change so color can be well controlled. This is usually the preferred method of dimming high current LEDs.

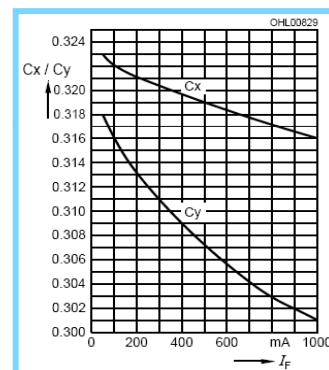
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Analog Dimming – Why Not?

Analog Dimming

- CCT provides the basis for “cool” white (more blue) and “warm” white (more red) - CCT shifts with I_F as well
- Most white LEDs are made off blue LEDs with yellowish phosphor coating
- CCT shifts are much easier to see than with colored LEDs (more yellow at low I_F and more blue at high I_F)



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Analog vs. PWM Dimming (3)

More Yellow



1W LED driven at 50 mA continuous

More Blue



Same 1W LED driven at 300 mA with 1/6th duty cycle (500Hz)

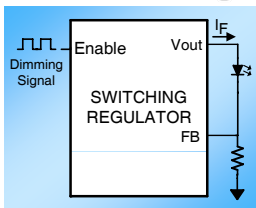
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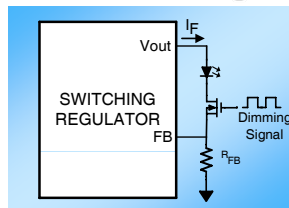
PWM Dimming Schemes

Enable Dimming



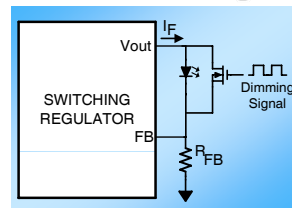
- I_F On/OFF through Enable/Disable
- Simple implementation
- Slow current transitions

Series Dimming



- I_F On/OFF through the series FET
- OK current transitions
- V_{out} overshoots, complex implementation

Shunt Dimming



- I_F In/Out through the shunt FET
- Super-fast current transitions
- High-power dissipation in the shunt FET

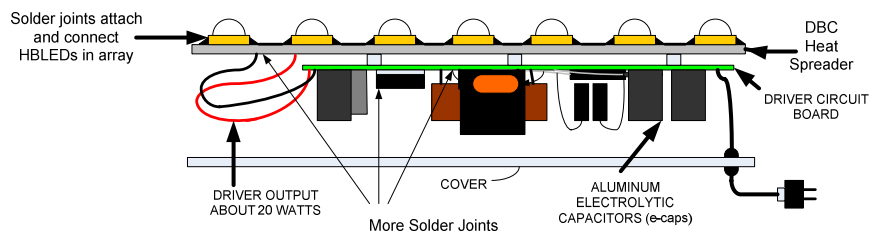
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Review of Reliability/Lifetime

- Every component limits lifetime – to some degree
- 3 types of components usually have the largest influence on ultimate lifetime
 - Non-solid electrolytic capacitors (e-Caps)
 - Solder joints
 - Optical isolation devices (opto-couplers)



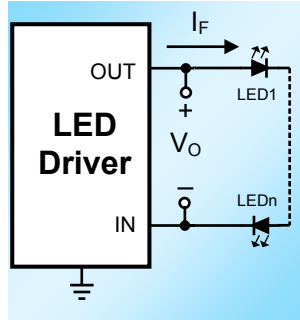
TEXAS
INSTRUMENTS

LED Configuration



TEXAS
INSTRUMENTS

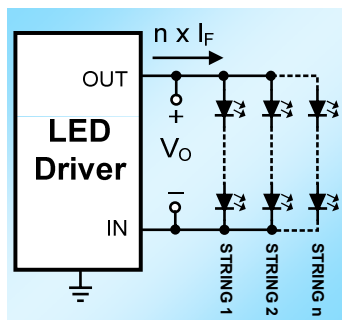
All in Series



- Pros:
 - Guaranteed current matching
 - Continues to operate if LEDs fail short circuit
- Cons:
 - Highest output voltage
 - Component selection thins as voltages go up
 - Safety standards get more strict
 - No more light if an LED fails open circuit

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Series-Parallel

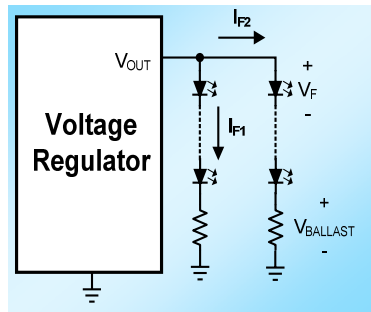


- Pros:
 - Lower V_O
 - Staying within safety limits
 - Continues to operate (poorly) if LEDs fail short circuit
- Cons:
 - No current matching
 - V_F varies from LEDs, even LEDs from same wafer
 - V_F drops with T_J , potential positive feedback loop

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Pitfall of Series-Parallel #1

- Ballast resistors work well with a voltage source and a low current LED
- The old way:



$$I_F = \frac{V_O - n \times V_F}{R_{BALLAST}}$$

- The tolerance of I_F improves:
- As I_F decreases
- As $R_{BALLAST}$ increases
- As $V_{BALLAST}$ increases

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Low Frequency (< 1 kHz)

- General and automotive applications
- More efficient: less transitions
- Duty cycle requirements not as strict: 10% to 90% is typical
- Usually achievable by using the DIM or EN pins

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High Frequency (> 10 kHz)

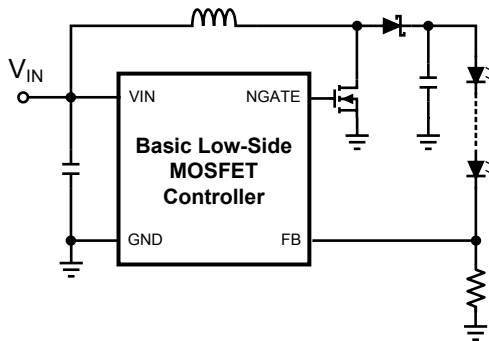
- Technical requirements force the users to high frequency
- High speed PWM dimming can be desirable in order to avoid certain frequency bands, such as audio
- Generation of white light from RGB in backlights, video projectors
- Loss of efficiency due to the transitions
- Some big questions...
 - How do we do this when LED current is very high?
 - How do we do this with various topologies?

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Current Sensing

Low-Side Sensing

- Easier to implement, easier to amplify
- With a controller, V_{O-MAX} can be 100V+
- $I_F = V_{REF} / R_{SNS}$

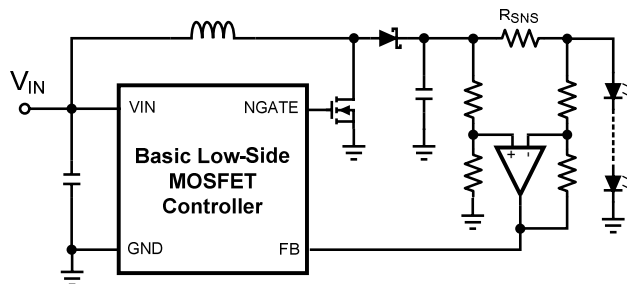


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High-Side Sensing

- | | |
|--|--|
| <ul style="list-style-type: none"> • Pros: <ul style="list-style-type: none"> – Continuous current if LEDs are shorted* – Last LED cathode connects to system ground | <ul style="list-style-type: none"> • Cons: <ul style="list-style-type: none"> – Requires differential sense with high common mode range – V_{O-MAX} is limited by sensing circuitry |
|--|--|



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Isolated or Non-isolated

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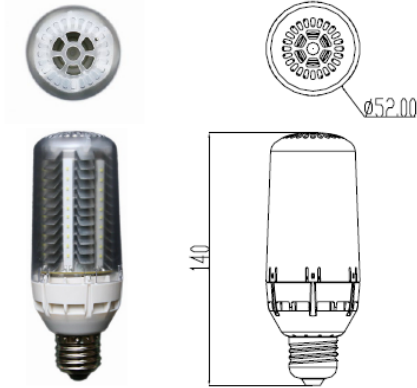
Safety of Lighting System

- 4KVac High Pot Test between Chassis & Terminals is required to meet safety standard in lighting system (EN60968/9)



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Non-Isolated Solution



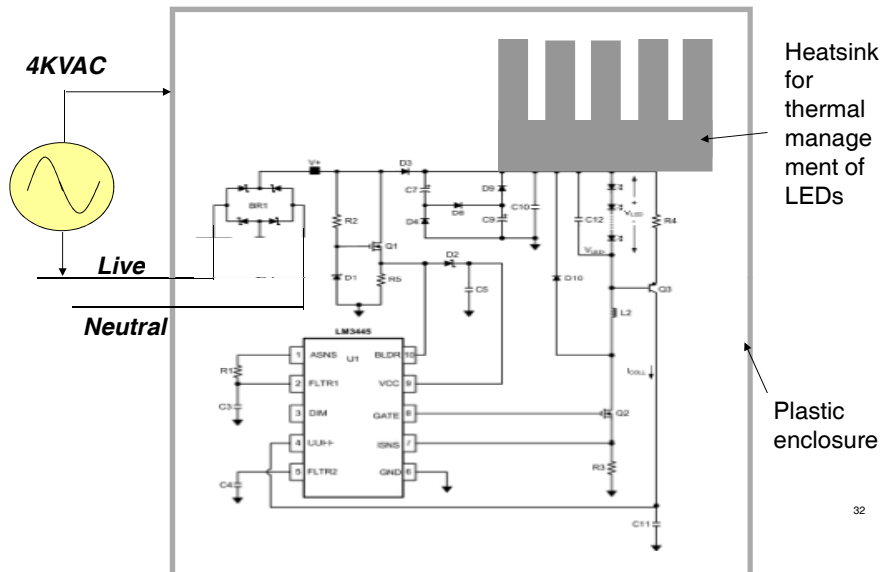
The LED drivers & heatsink of LEDs is fully encapsulated by the plastic case.

Like the conventional CFL light bulb, The plastic enclosure as the insulator, the heatsink/metal & electronic devices are non-accessible by Human Finger

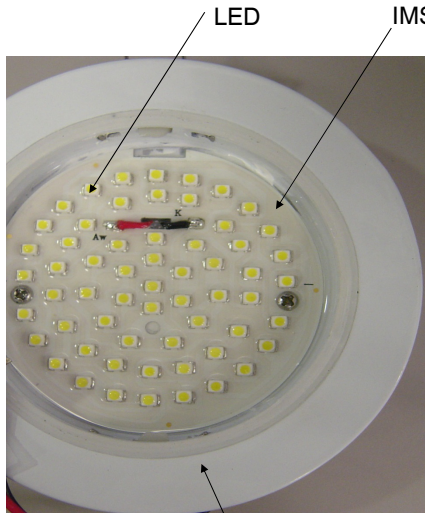
Can simply employ Non-isolated LED driver to pass 4KVAC test.



Non-Isolated Solution (II)



Why need Isolated Solution?



For higher power GI applications, such as downlights, the IMS (insulated metal substrate) Board is directly attached to the metal casing of fixture for optimizing the thermal management of LED.

Metal/Heatsink can be accessible by Human.

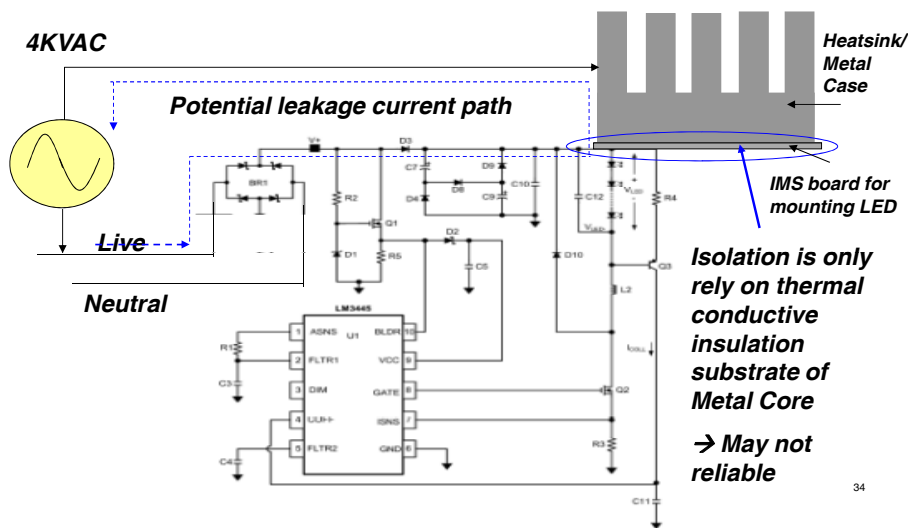
And, the insulated layer is only relied on the thermal conductive insulated substrate of Metal Core Board.

Metal Case



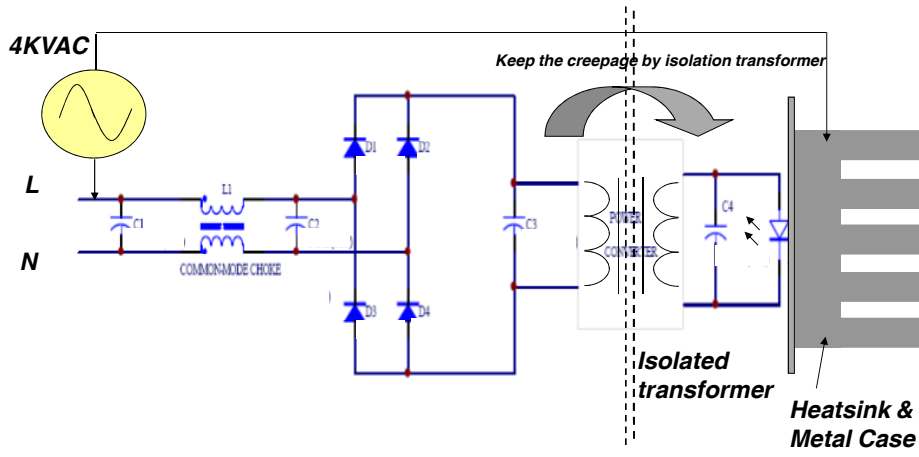
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Why need Isolated Solution? (II)



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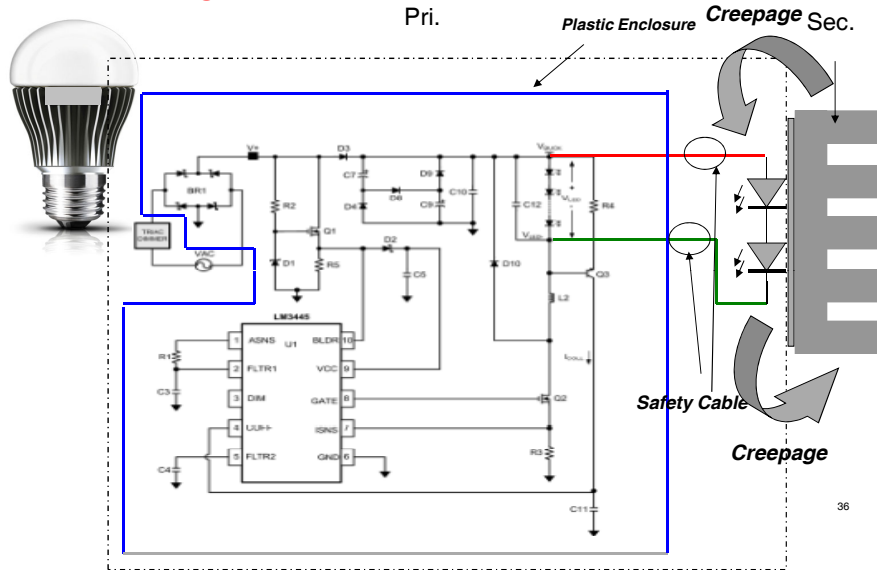
Isolated AC/DC LED Driver



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How can we meet safety requirement for non-isolated driver in LED light bulb /w metal enclosure?



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What is Traic Dimmer?

The Basics of Triac

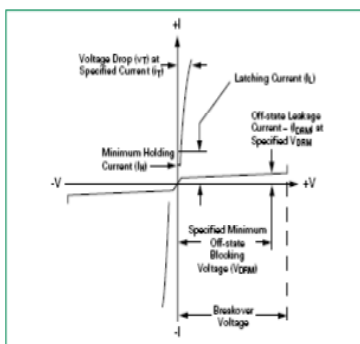


Figure AN1001.13 V-I Characteristics of Triac Device

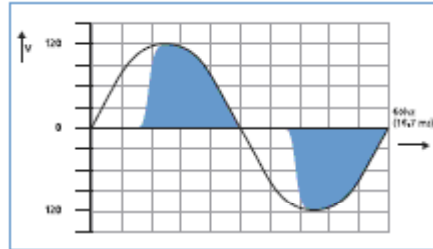
Three general methods are available to switch Thyristors to on-state condition:

- (1) Applying Proper Gate Signal
- (2) Exceeding Thyristor dv/dt characteristics
- (3) Exceeding voltage break-down point

In the below discussion, we are focus on (1)

Triac Dimmer Characteristics

- Triac requires a resistive load to fire
 - Drip current of 10-15mA
 - Once Triac fires, drip current can be removed to increase efficiency
- Output is a sampled segment of the offline AC waveform
 - Based on the firing angle set by the Triac dimmer

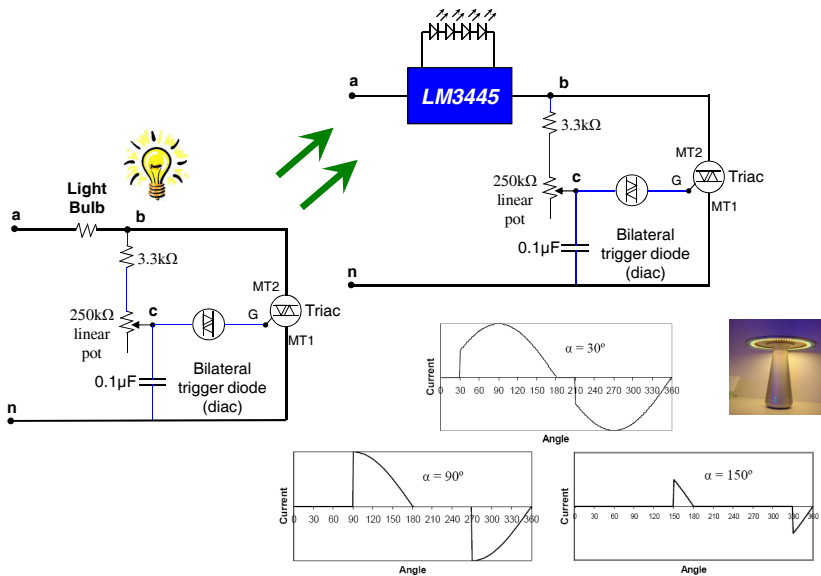


Forward phased Triac-dimmed waveform

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Triac Dimming Circuit



Switch-On the Thyristor by Proper Gate Signal

- To turn on the Thyristor, Gate signal must exceed IGT and VGT requirements of the Thyristor used.
- Triac (bilateral device) can be turned on with gate signal of either polarity; however, different polarities have different requirements of IGT and VGT which must be satisfied.

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Latching Current of the Triac

- Latching current (I_L) is the minimum principal current required to maintain the Thyristor in the on state immediately after the switching from off state to on state has occurred and the triggering signal has been removed.
- Latching current can best be understood by relating to the “pick-up” or “pull-in” level of a mechanical relay.

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Holding Current of Triac

- Holding current (I_H) is the minimum principal current required to maintain the Thyristor in the on state.
- Holding current can best be understood by relating it to the “dropout” or “must release” level of a mechanical relay.

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What is Holding Current?

- Example :
 - Suppose Triac Dimmer uses BTA06-TW

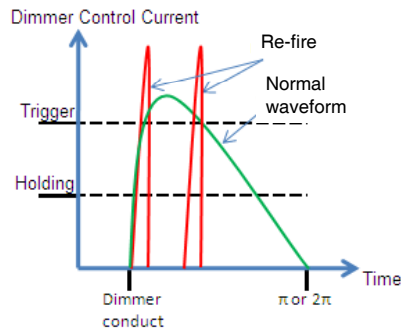
Symbol	Test Conditions	Quadrant		BTA06 / BTB06				Unit
				TW	SW	CW	BW	
I_{GT} (1)	$V_D = 12\text{ V}$ $R_L = 30\ \Omega$	I - II - III	MAX.	5	10	35	50	mA
V_{GT}		I - II - III	MAX.	1.3				V
V_{GD}	$V_D = V_{DRM}$ $R_L = 3.3\text{ k}\Omega$ $T_j = 125^\circ\text{C}$	I - II - III	MIN.	0.2				V
I_H (2)	$I_T = 100\text{ mA}$		MAX.	10	15	35	50	mA
I_L	$I_G = 1.2\ I_{GT}$	I - III	MAX.	10	25	50	70	mA
		II		15	30	60	80	

Max. holding current $I_H = 10\text{mA}$



Common Problem with Triac Dimmer

- If holding current does not flow through the triac continuously, the triac will re-fire at same conduction period.



Summary of Triac Operation

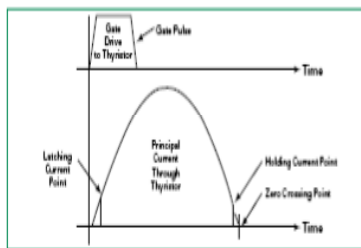


Figure AN1002.6 Latching and Holding Characteristics of Thyristor

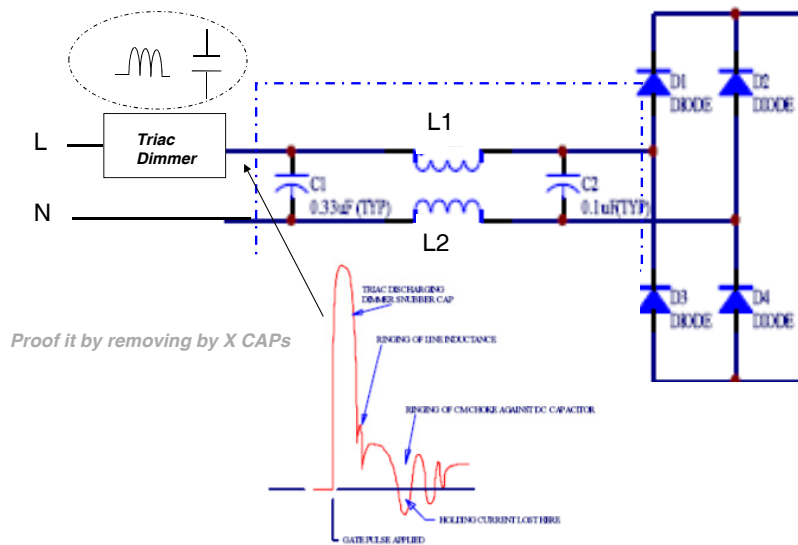
- 1) To turn on the Triac, Gate signal must exceed specified IGT and VGT requirements
- 2) Latching current (I_L) is required to maintain the Triac in the on state immediately after the switching from off state to on state has occurred and the triggering signal has been removed.
- 3) Then, Holding current (I_H) is the required to maintain (hold) the Thyristor in the on state
- 4) As the cathode to anode current of Triac is less than specified holding current, the Triac is switched to off-state.

Why flickers?

- As mentioned before, not just holding current, the input EMI filter interact with different types of triac dimmers also could misfire the triac.....

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Standard SMPS EMI filter interacting with Triac Dimmers

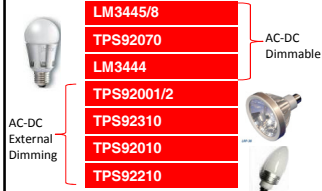


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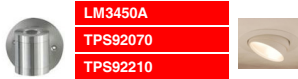
TI Lighting Power Products at a Glance

Light Bulbs & Low Power Luminaries

B10, GU10, A19, PAR20-38

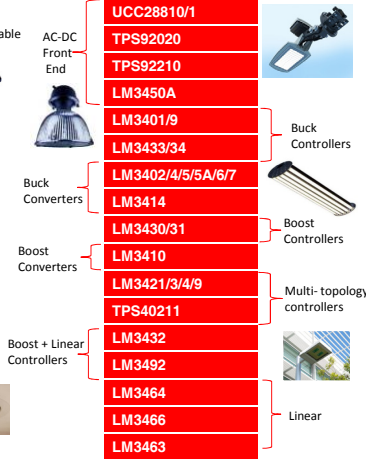


Architectural, Wall Washers, Sconces, Downlights



High Power Wide Area Luminaries

Street Light, High Bay, Parking, Pathway, Troffers



Automotive

Exterior, Interior & Infotainment backlighting



Q & A?

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