Challenges on Solid-State Lighting Offline Driver Design

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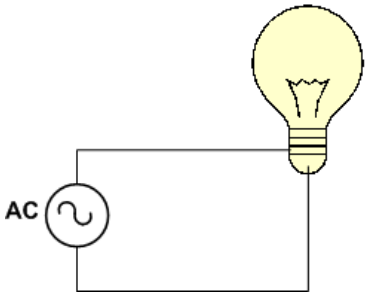
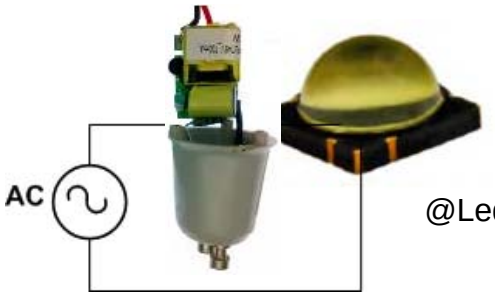
Contents

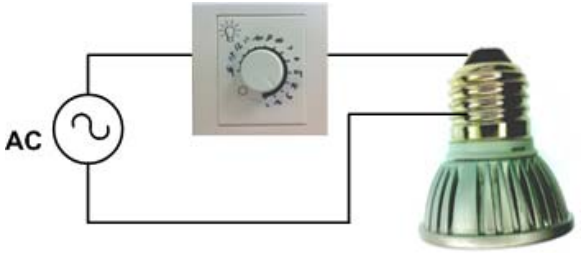
- Review the challenges with replacing incandescent lamps
- Review LED lamp driver basics
- Approaches to improve power factor
- Isolated solutions without opto-coupler
- Dimmable LED driver solutions

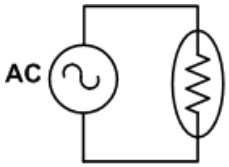
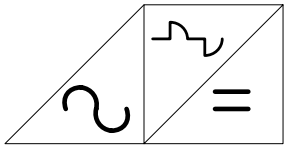
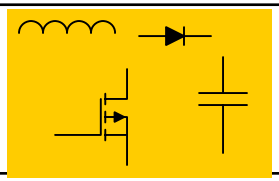
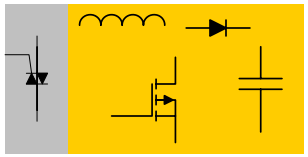
SSL LED Lamps



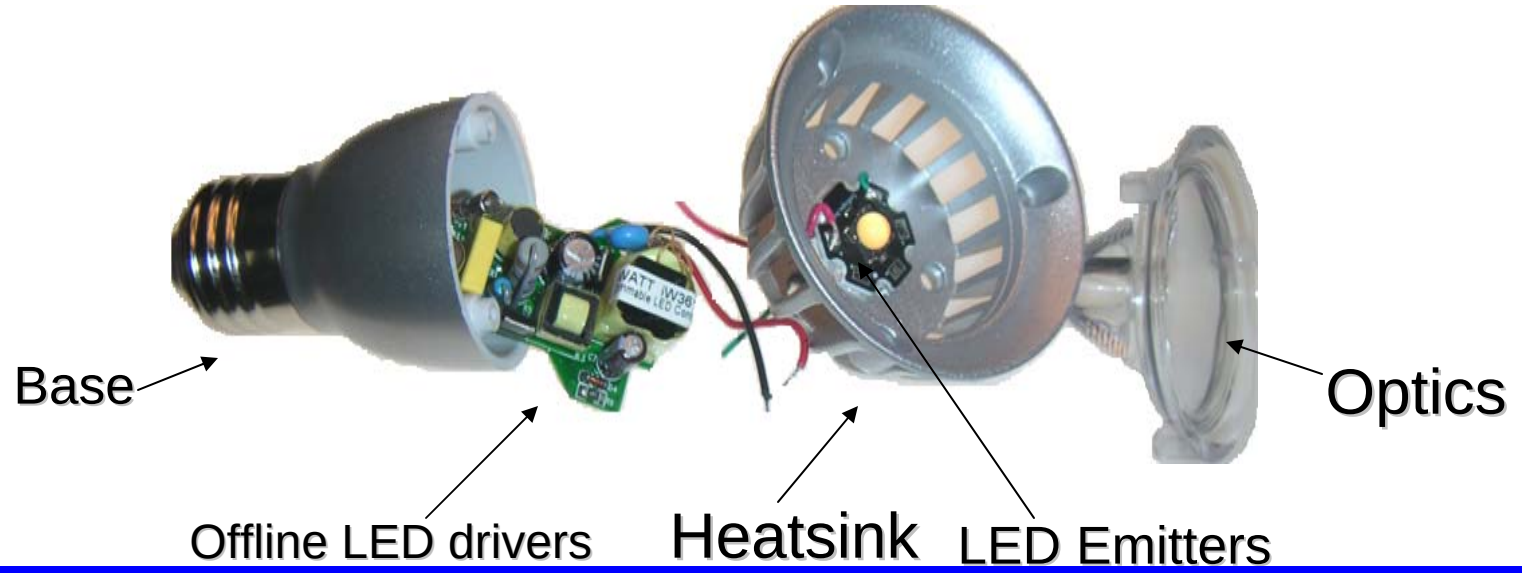


@LedEngin



Incandescent Lamps	DC-LED Lamps	Dimmable DC-LED Lamps
		
Pure resistive load		
Phase-out	Switch-mode Power Drivers	Switch-mode Power Drivers
Simple	EMI, Size, Safety Thermal	Various Dimmers EMI, Size. Safety, Thermal

Offline LED Lamp Basics



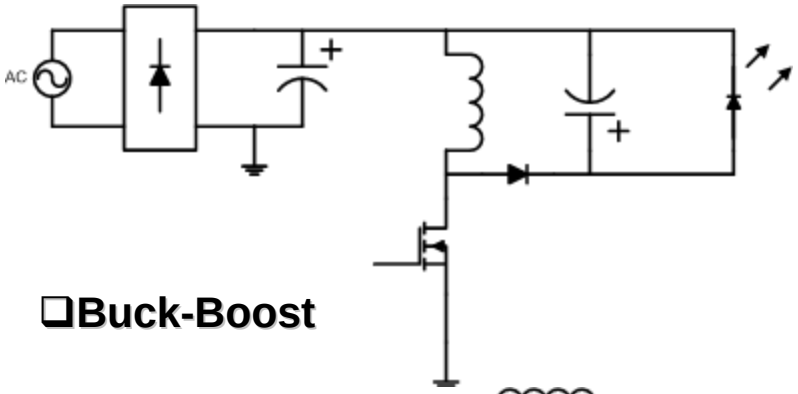
Luminous efficacy =
(LED luminous efficacy) x (Driver efficiency) x (LED thermal efficiency) x (Optics efficiency)
Where LED Luminous Efficacy is visible lumens/optical watt

Maximum allowed Input Power	Total Lumens	LED luminous efficacy	Thermal Efficiency	Optics and Fixture	Required Driver Efficiency
(W)	lms	lms/W	(%)	(%)	(%)
10	900	150	85%	85%	83%
17	1500	150	85%	85%	81%

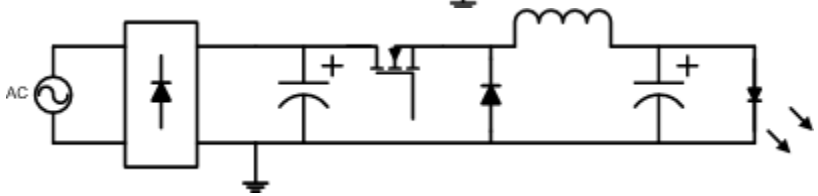
Offline LED Lamp Driver Topologies

DESIGNING WITH LEDs
EDN design
FULL-DAY TECHNICAL SEMINAR AND WORKSHOP

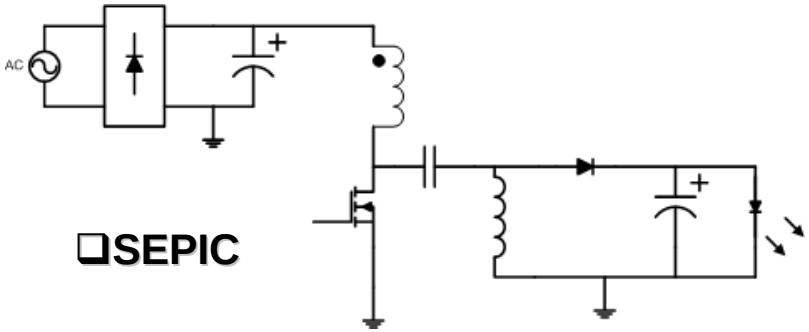
Non-isolated



❑Buck-Boost

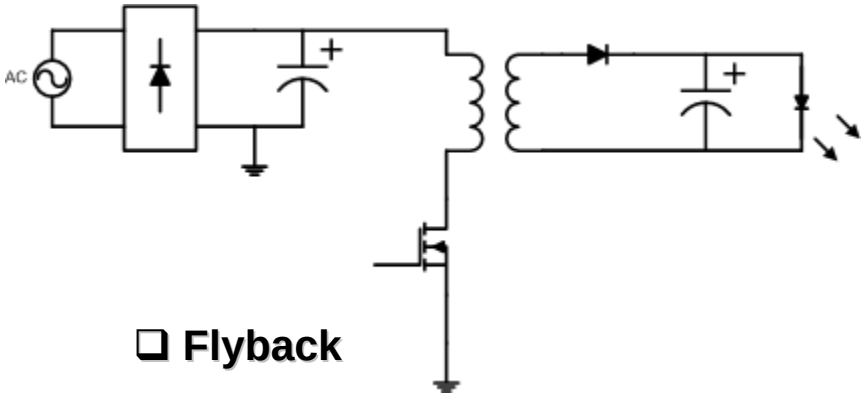


❑buck



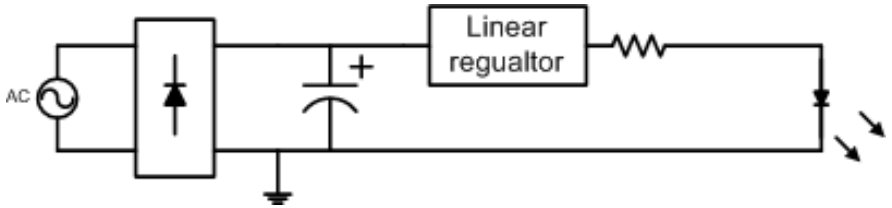
❑SEPIC

Isolated



❑ Flyback

Linear

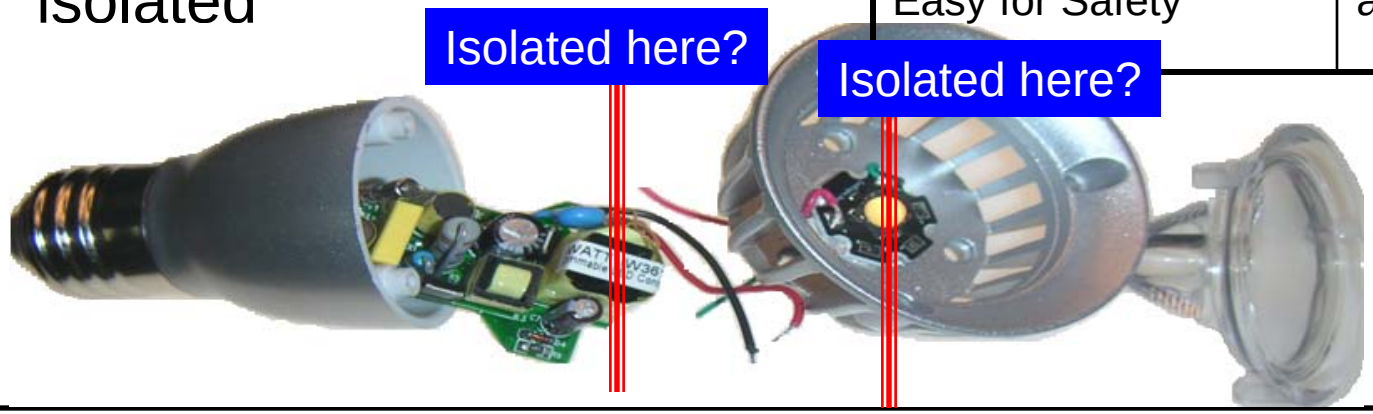


Driver should be Isolated or Non-isolated?

DESIGNING WITH LEDs EDN design
FULL-DAY TECHNICAL SEMINAR AND WORKSHOP

- Isolation between AC socket and the exposed surface is required
- Isolation can be done in the driver board by transformer
- Or isolation can be done between the emitter and heatsink
- Or the whole lamp is isolated

Isolated drivers	Non-isolated drivers
Suitable for high-power high-current low-voltage	Suitable for low-power high-voltage low-current
More components, less power efficiency	Simple, low cost
Easy for mechanical design and thermal management	Easy for electric driver board design
Easy for EMI design, Easy for Safety	Challenges for EMI and safety



SSL LED Standards Relate to the Driver

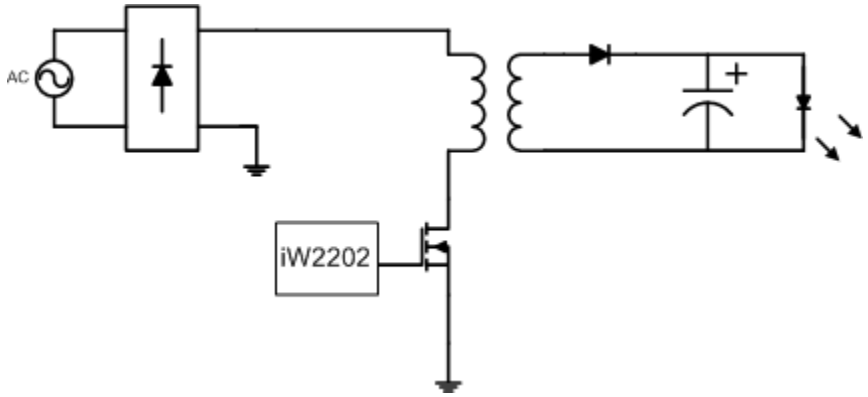
- ENERGY STAR® Program Requirements for Integral LED Lamps
- FCC requirements
  - 47 CFR part 15
    - Class A and Class B
- Harmonic Emission limits and related power quality
  - ANSI C82.77-2002
  - IEC 61000-3-2
- Safety
  - UL8750
  - IEC 60950 Part 1
- Line Transient protections (Lighting Surge)
  - IEEE C62.41-1991; Class A, 100kHz ring wave, 2.5kV combine
- Audible Noise
  - Class A

Challenges to Promote LED lamp

- LED lamp challenges to be overcome in order to enter into home lighting market:
  - **Cost**
    - Driver BOM cost should be below 15% of total lamp cost
  - **Thermal efficiency**
    - Any milliwatt loss inside driver certainly reduces the efficiency (lumens per input watt) and reliability.
  - **Reliability and Life time**
    - Multi-layer protections for OTP, OCP, short circuit, open circuit
    - Single fault protection for any case
    - Less component count
  - **Regulatory and Safety**
    - EMI
    - Power Factor and Harmonic
    - Line Isolation and less leakage current
  - **Dimmable**
    - No visual Flicker
    - Wide Dimming Range

Approaches to Improve Power Factor

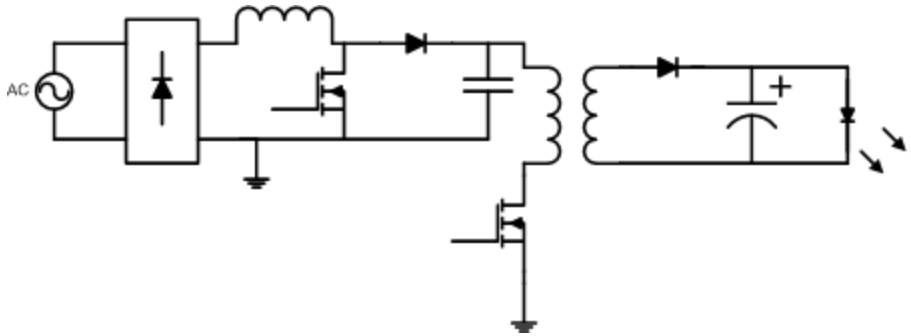
- Basic Flyback: Single-stage Solution



Advantage
- **Simple**
- **No bulk e-cap**

Disadvantage
- **Line frequency ripple current**

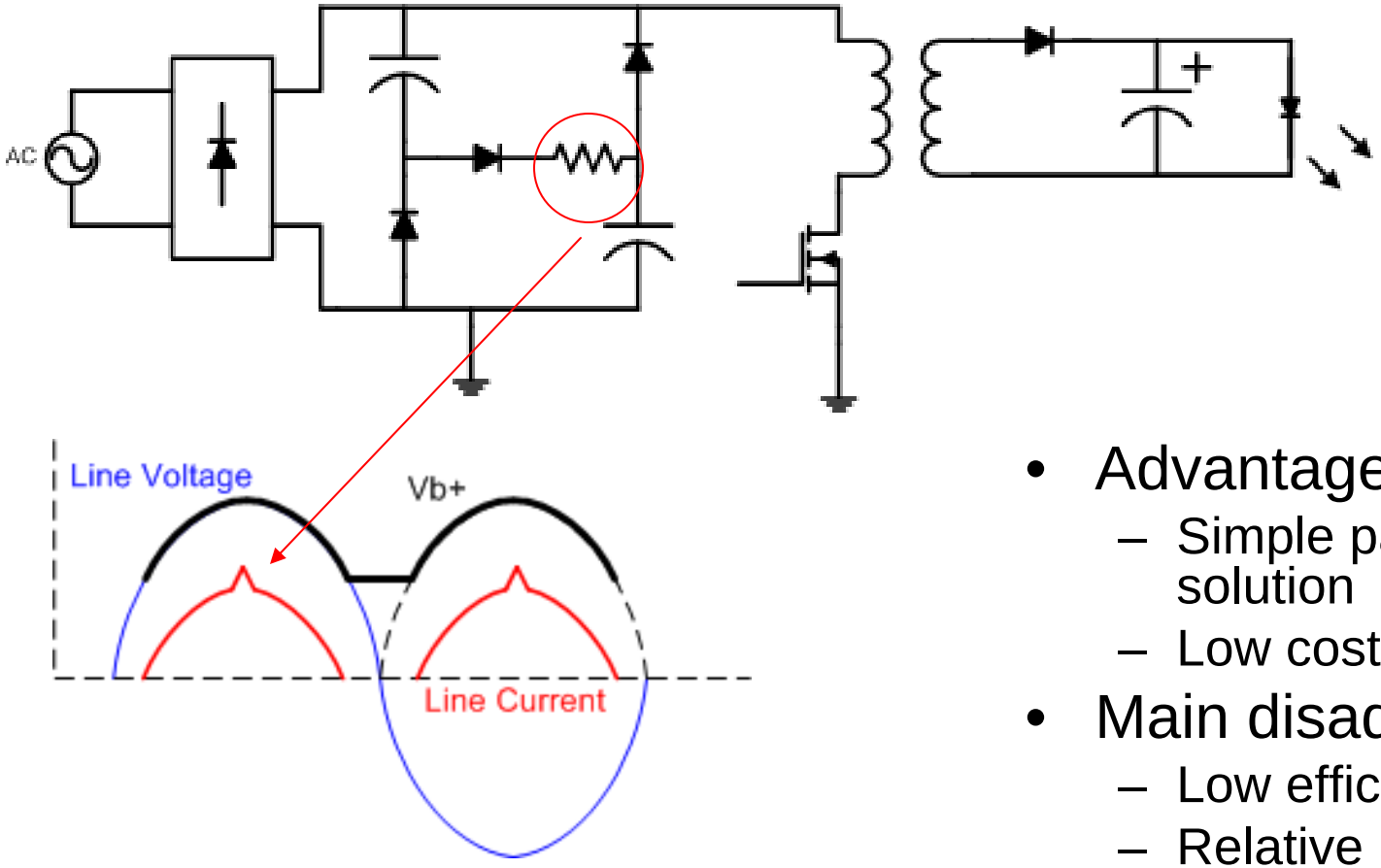
- Boost + Flyback: Two-stage solutions



Advantage
- **No flickers**
- **High PF**

Disadvantage
- **Cost**

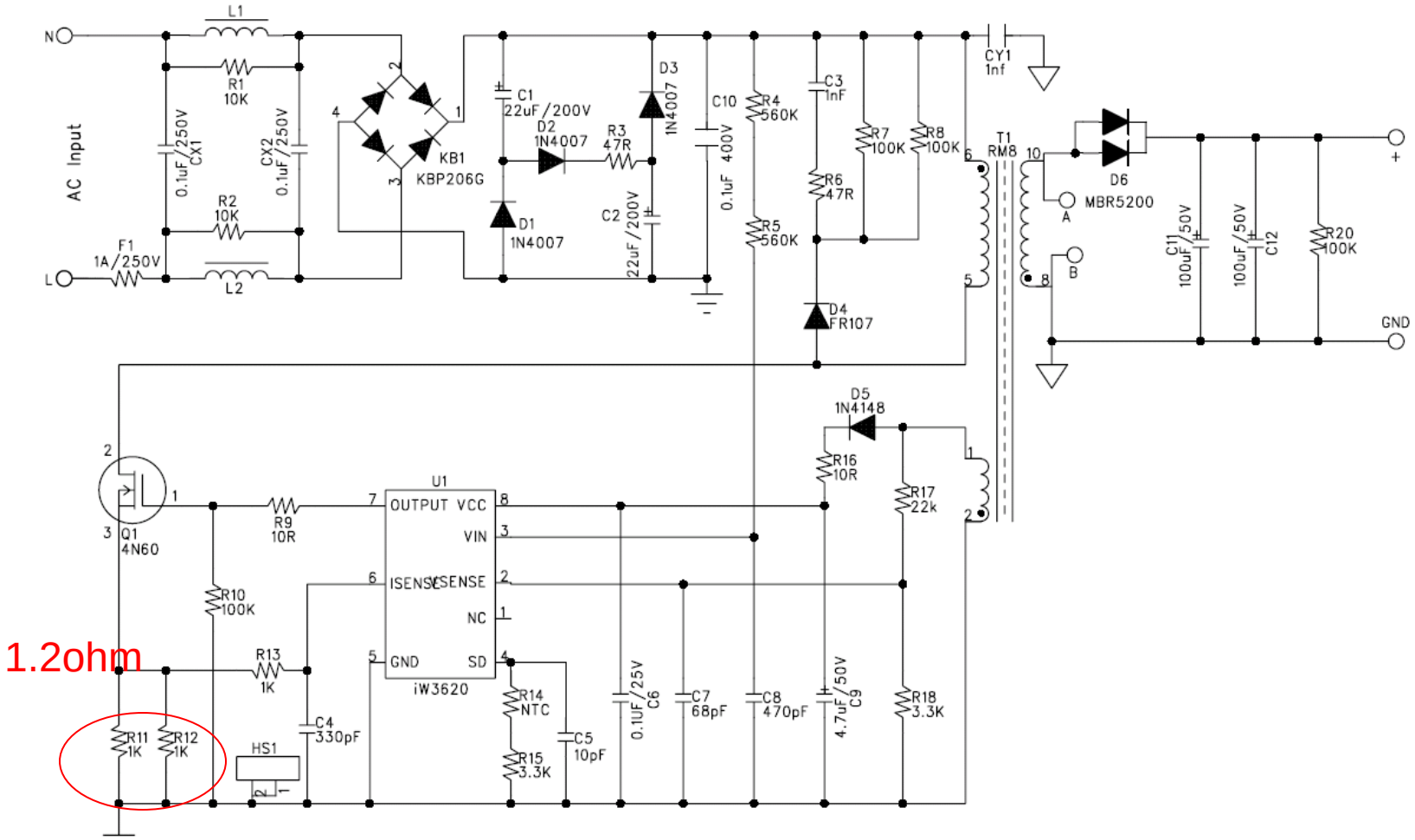
Simple Passive Valley-fill PFC Circuits



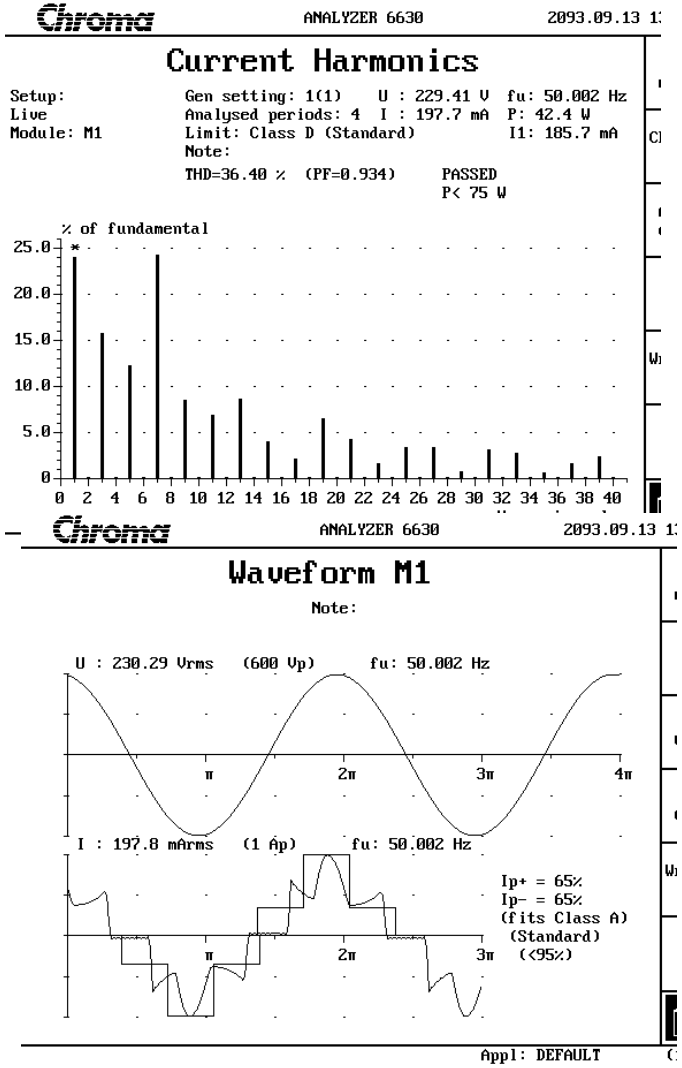
- Advantage
  - Simple passive solution
  - Low cost
- Main disadvantage
  - Low efficiency
  - Relative high THD

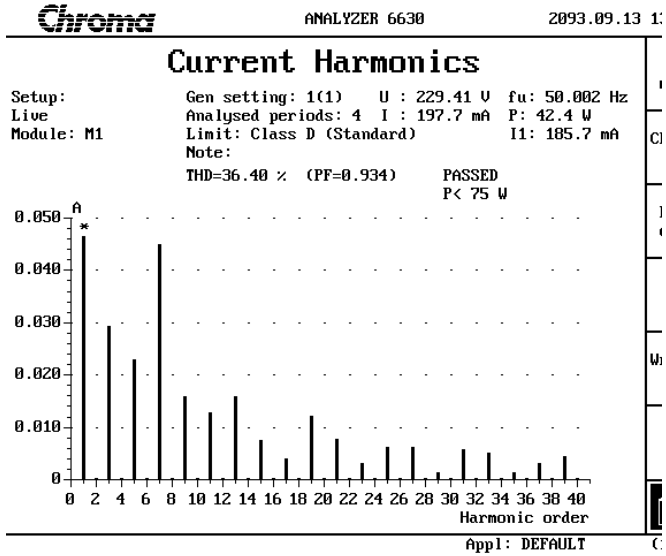
Example:
Valley-fill filter LED Driver

- **iW3620 for 15-30W LED driver**



Measurements:
Power Factor and THD



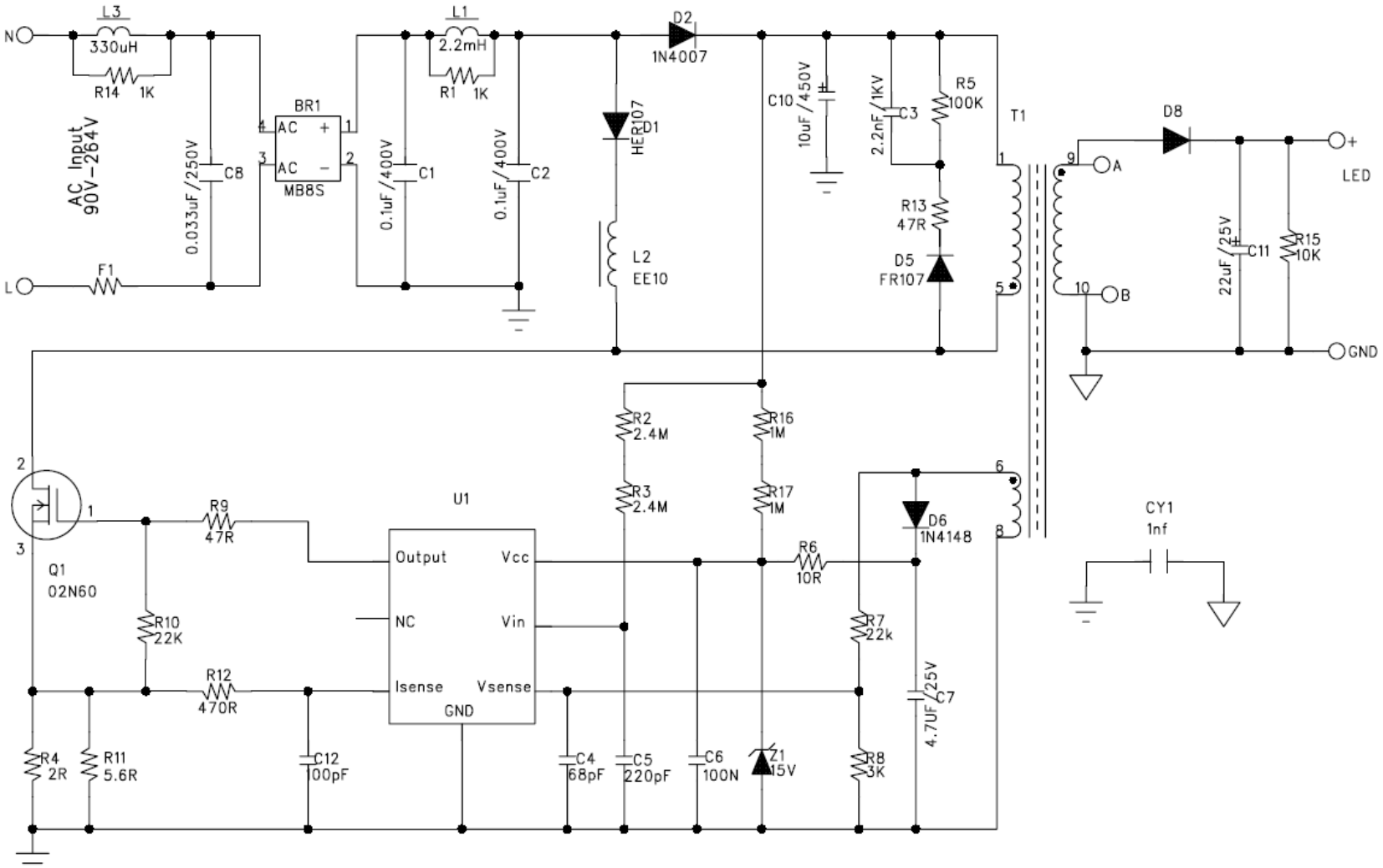


Vin__230V PF=0.93

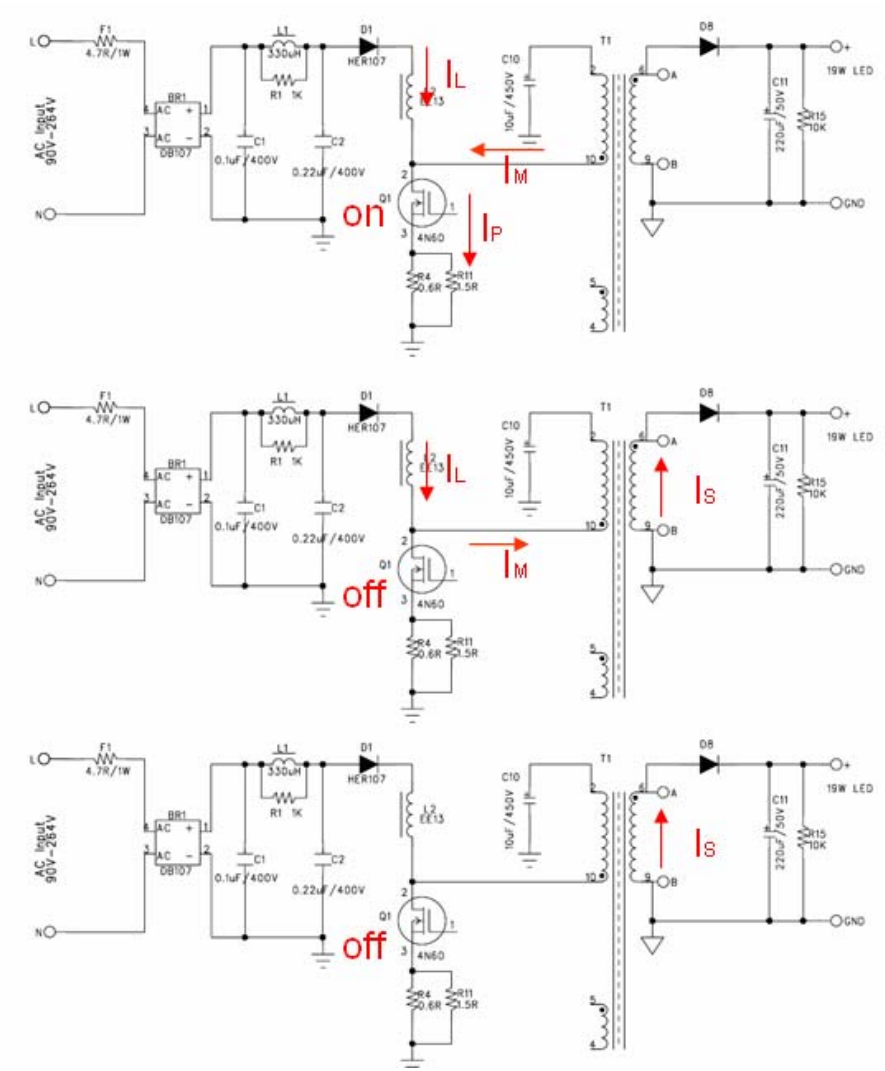
Harmonic__3rd 15% 5th_25%

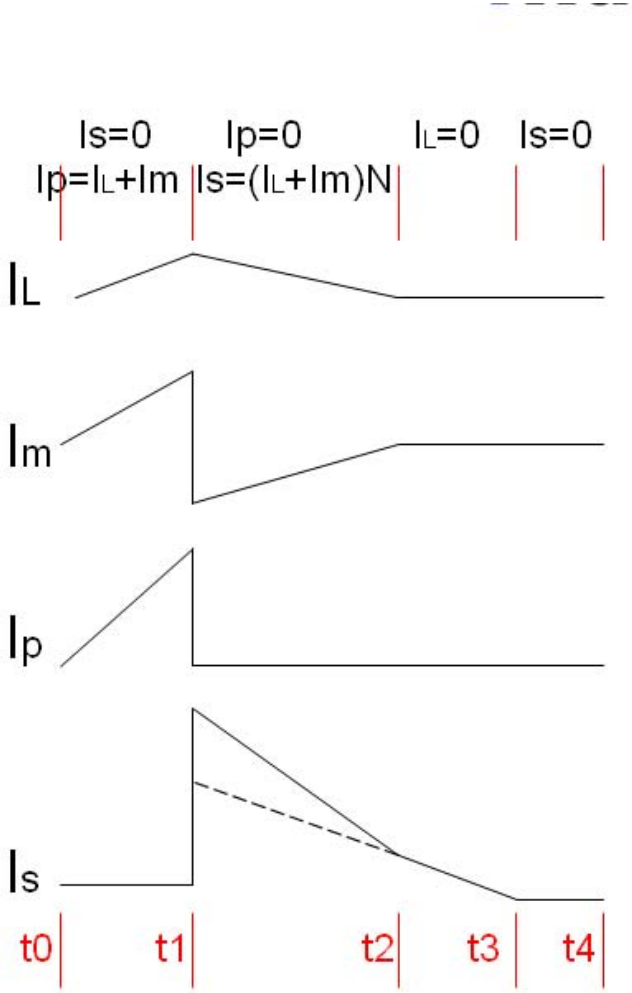
$$PF = \frac{\cos\varphi}{\sqrt{1+THD^2}}$$

A simple SEPIC Active High PF Design



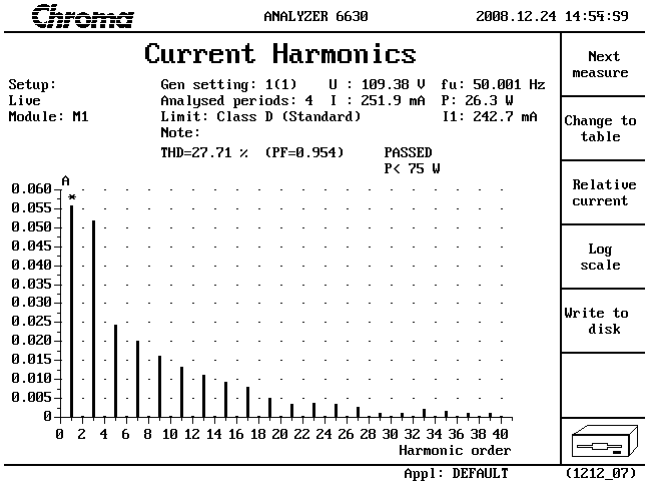
Operations


AC Input 90V~264V
on
off
off
IL
IM
IP
IS
19W LED
GND

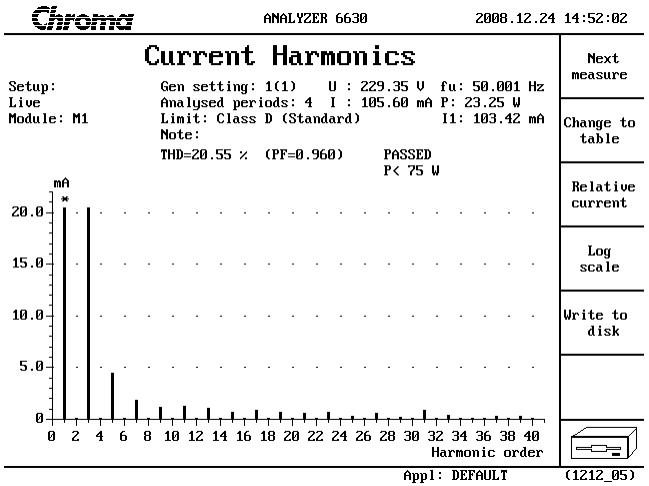

Is=0
Ip=0
IL=0
Is=0
Ip=IL+Im
Is=(IL+Im)N
IL
Im
Ip
Is
t0
t1
t2
t3
t4

Measurements:
Power Factor and THD

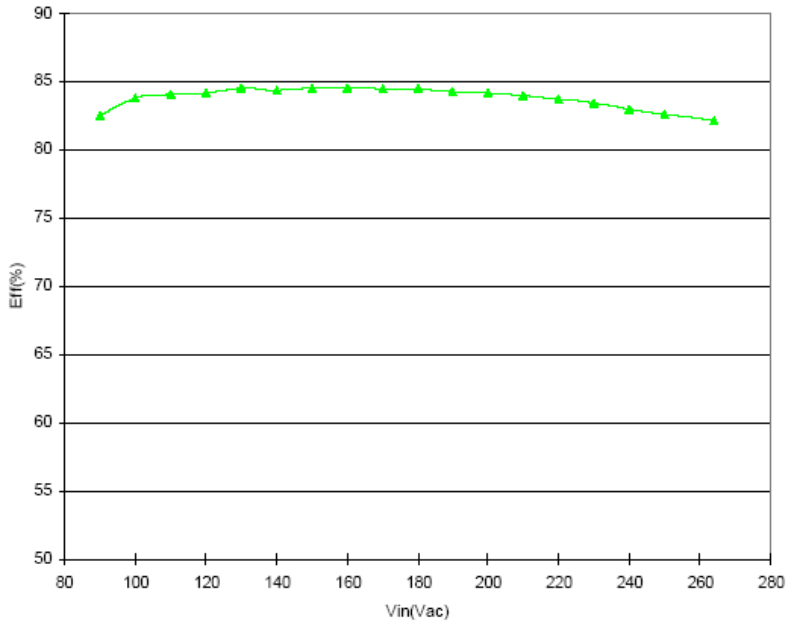
- **Active PFC with iW3620**



Vin__110V PF=0.95 Harmonic__3rd 22% 5th_10%



- **Efficiency**



Vin__230V PF=0.96

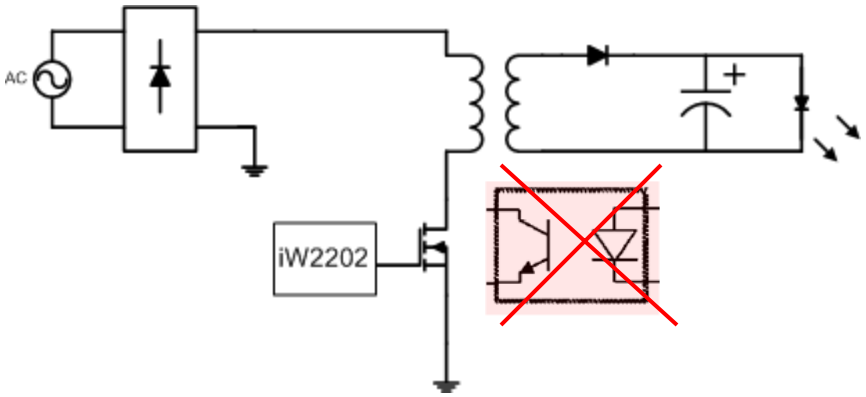
Harmonic__3rd 20% 5th_5%

Isolated solutions without Opto-coupler

- Isolated Solutions has many benefits to optimize the total cost-performance tradeoff
- Opto-coupler is typically used for isolated-solution to control the LED current; It becomes the weak component that reduces the life time of LED lamps.
- Primary-side constant current regulation eliminates the opto-coupler, and can also precisely control the LED current

Benefits on Primary-side control

- Line Isolation
  - Easy for heat sink design
  - Easy for heat spreading
  - Easy to meet safety regulation
- More reliable and longer life time
  - No opto
  - No Y-cap
- High Efficiency design
  - Isolated current transformer is easy for optimize efficiency



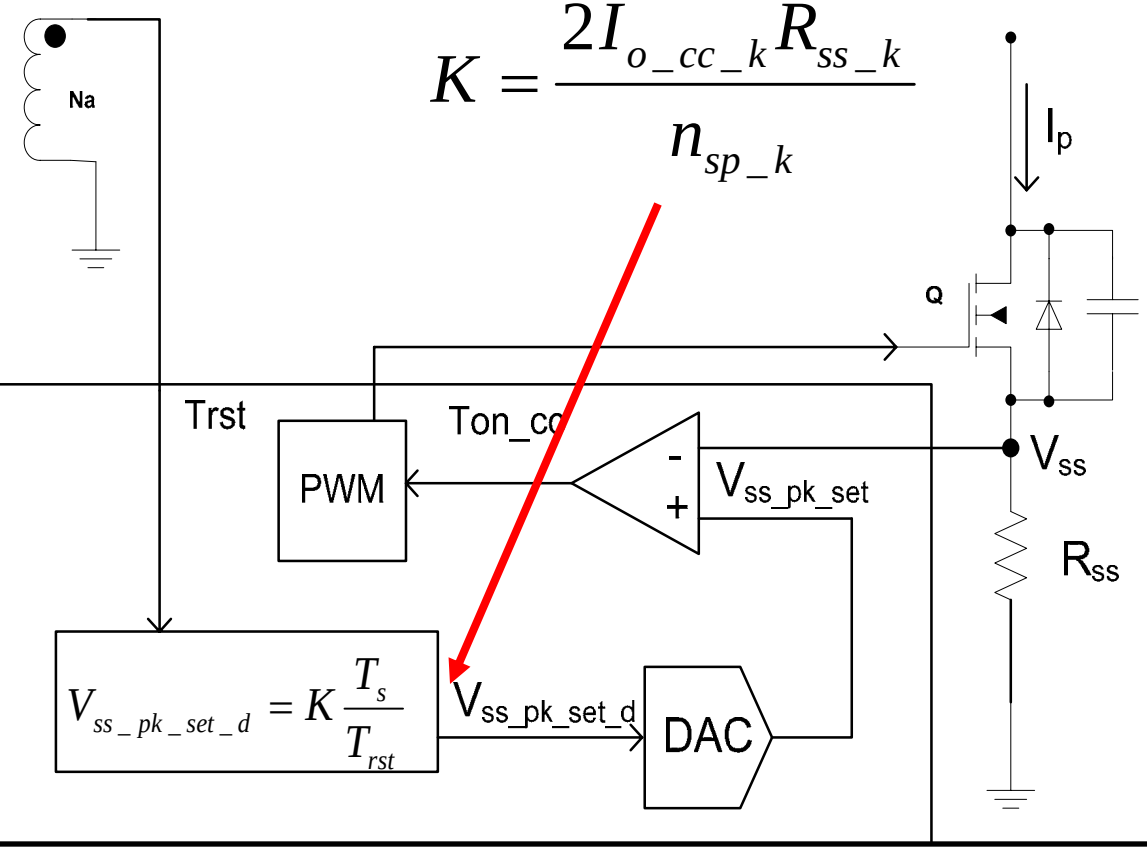
Digital Power Control on LED Constant Current Regulation

$$I_o = \frac{I_{pri\_pk} N_{ps}}{2} \frac{T_{rst}}{T_s}$$

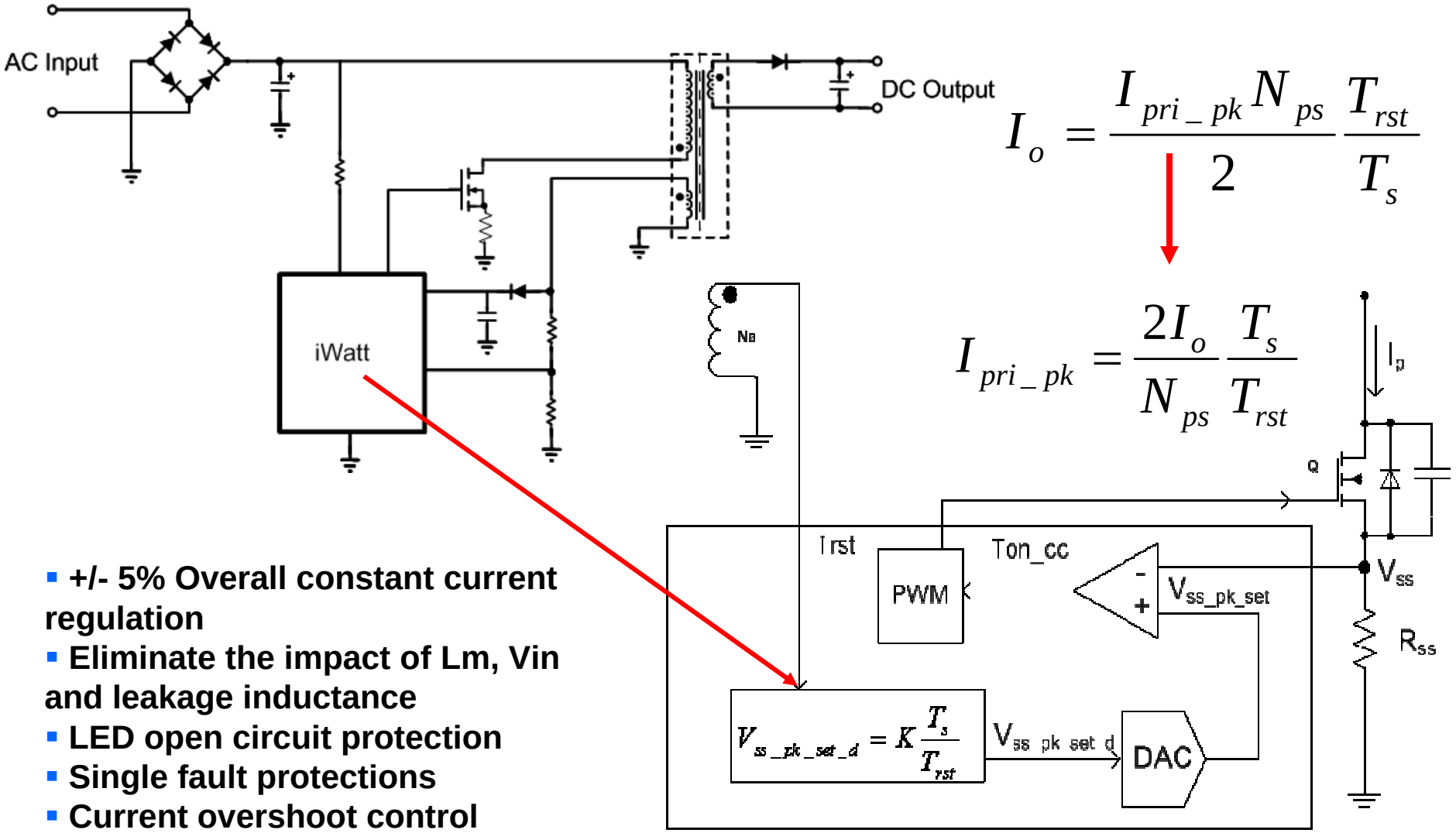
$$I_{pri\_pk} = \frac{2I_o}{N_{ps}} \frac{T_s}{T_{rst}}$$

Directly use primary current information.

$$K = \frac{2I_{o\_cc\_k} R_{ss\_k}}{n_{sp\_k}}$$



Adaptive Primary-side LED Constant Current Regulation



$$I_o = \frac{I_{pri\_pk} N_{ps}}{2} \frac{T_{rst}}{T_s}$$

$$I_{pri\_pk} = \frac{2I_o}{N_{ps}} \frac{T_s}{T_{rst}}$$

$$V_{ss\_pk\_set\_d} = K \frac{T_s}{T_{rst}}$$

- **+/- 5% Overall constant current regulation**
- **Eliminate the impact of Lm, Vin and leakage inductance**
- **LED open circuit protection**
- **Single fault protections**
- **Current overshoot control**

Intelligent Digital Power Control Benefits

- **Digital Primary-Feedback Technology** ***Patented***
  - No Opto, No TL431, No current sensor, No secondary control circuits

❑ **Better performance than traditional design**

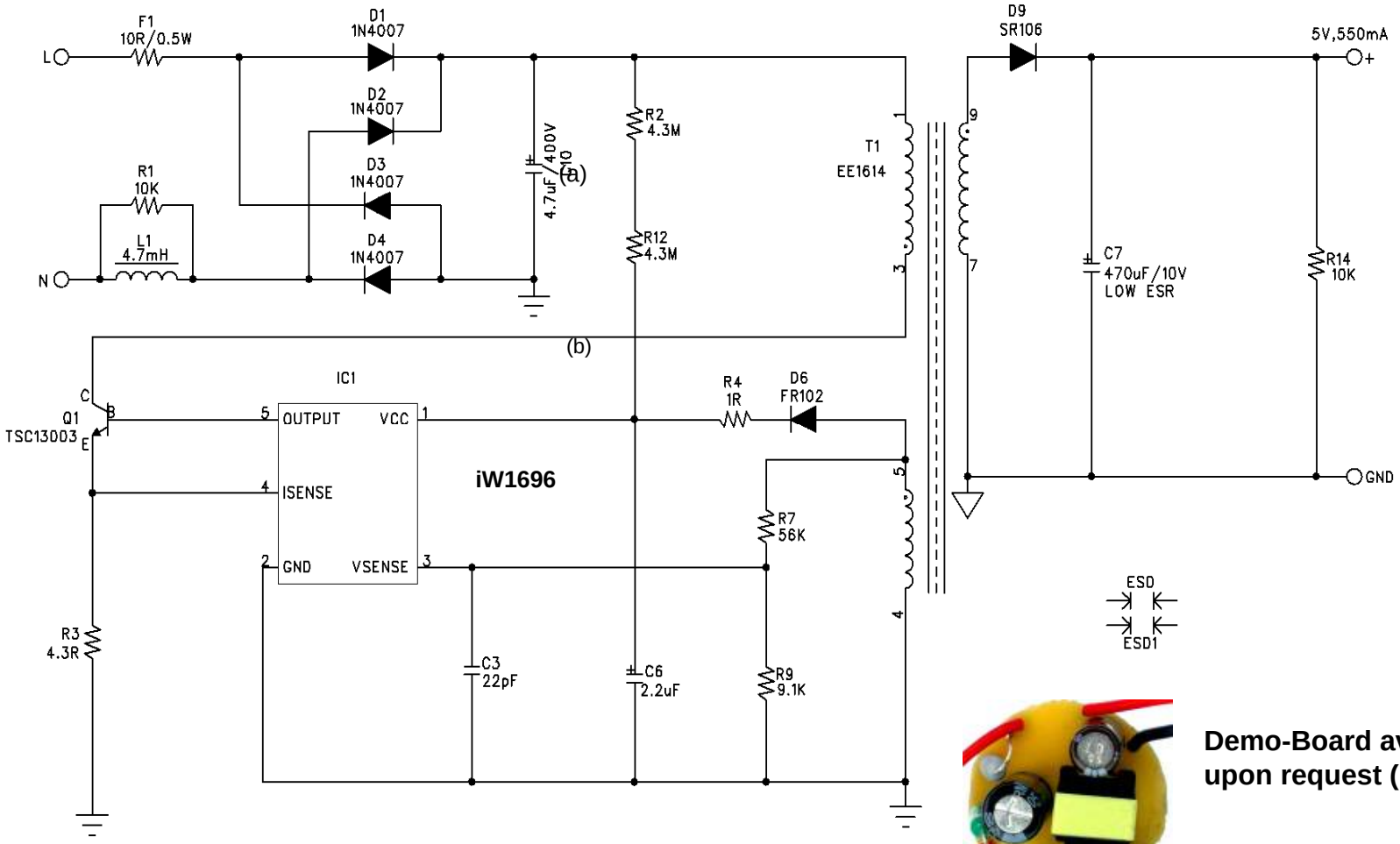
- **Adaptive cycle-by-cycle Digital Regulates Constant Current**

- **Multi-layer advanced protection features**
  - Isense short protection and other single-point fault protections
  - Brown-out / recovery
  - OVP, UVP, short circuit,

- **More**…
  - Low cost, Less components
  - More reliable

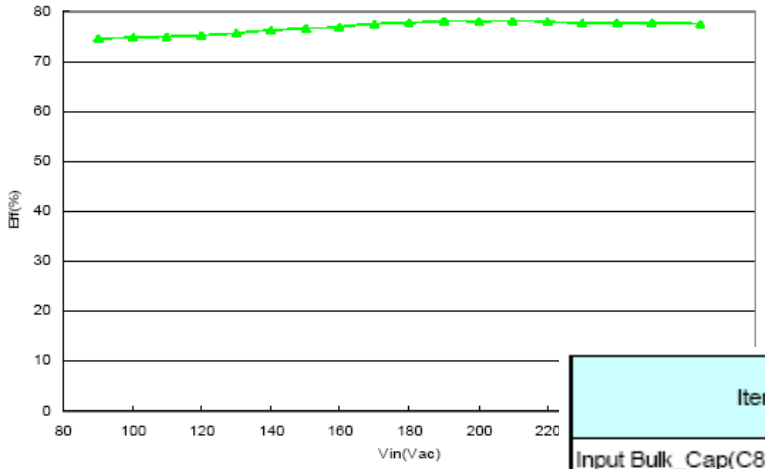
Example:
Low-cost LED Driver for 1~3W

DESIGNING WITH LEDs
EDN design
FULL-DAY TECHNICAL SEMINAR AND WORKSHOP



Demo-Board available upon request (1-2W)

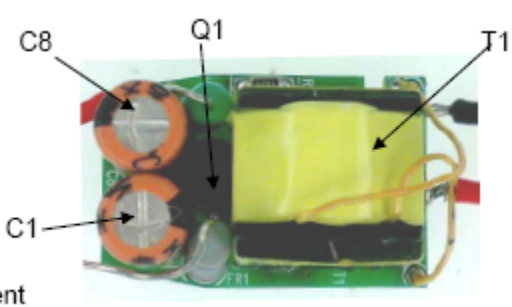
Measurement: Efficiency and Thermal

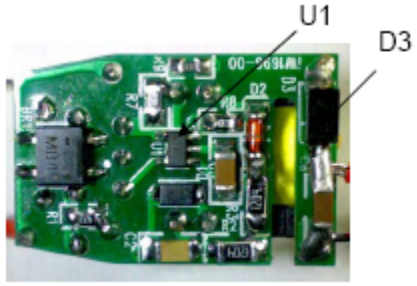


- **Efficiency**

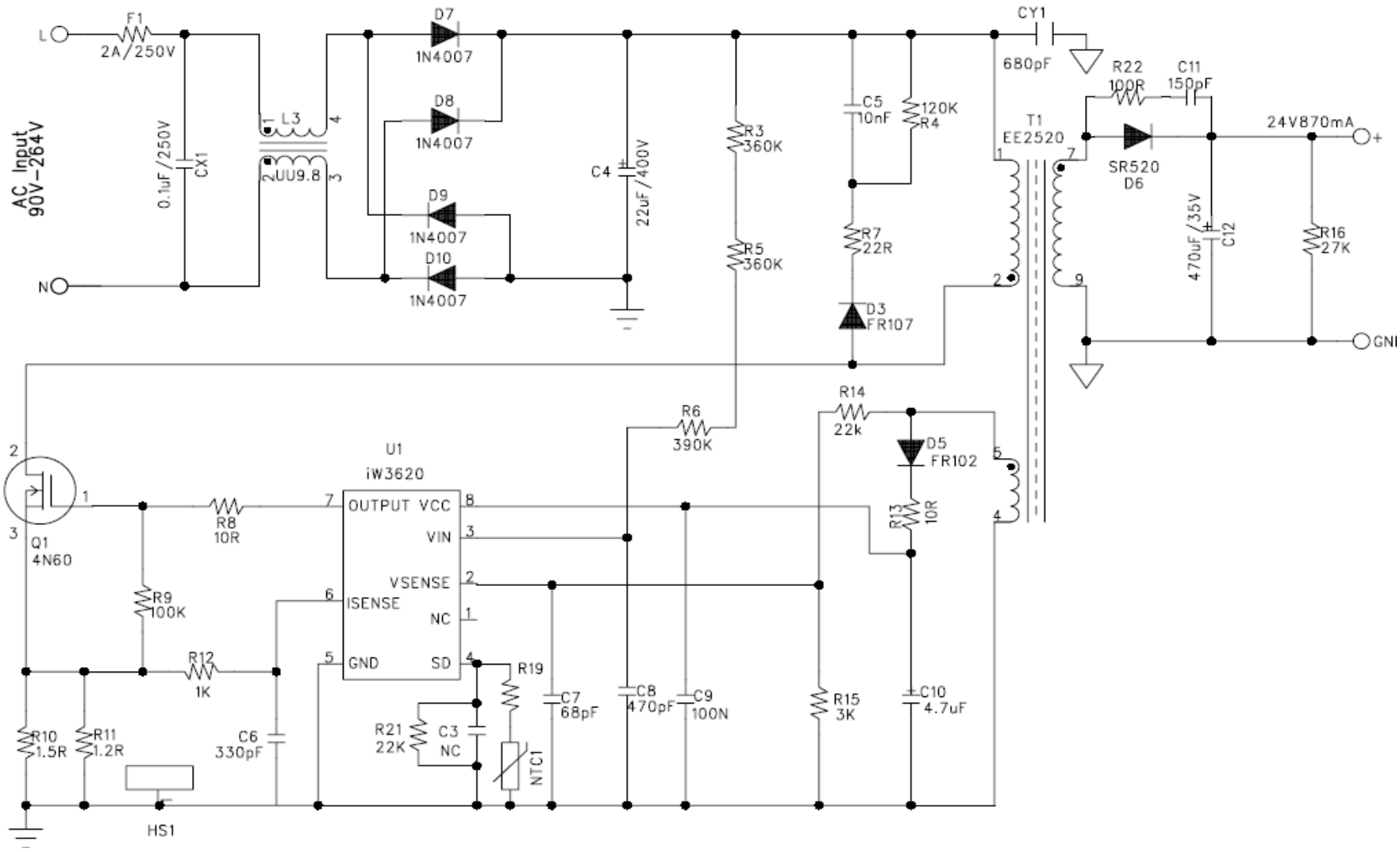
- **Temperature**

Item	V_{IN}=90Vac, 3X1W LED		V_{IN}=264Vac,3X1W LED	
	Temp.(℃)	Rising Temp. (℃)	Temp.(℃)	Rising Temp. (℃)
Input Bulk_Cap(C8)	78	13	73	10
Input Bulk_Cap(C1)	80	15	74	11
IC1(iW1696)	75	10	74	11
Transformer(T1)	85	20	84	21
Power Transistor(Q1-BV42)	88	23	86	23
Output Schotty Diode(D9)	92	27	90	27
Ambient (GU10 Housing) Temp.	65		63	



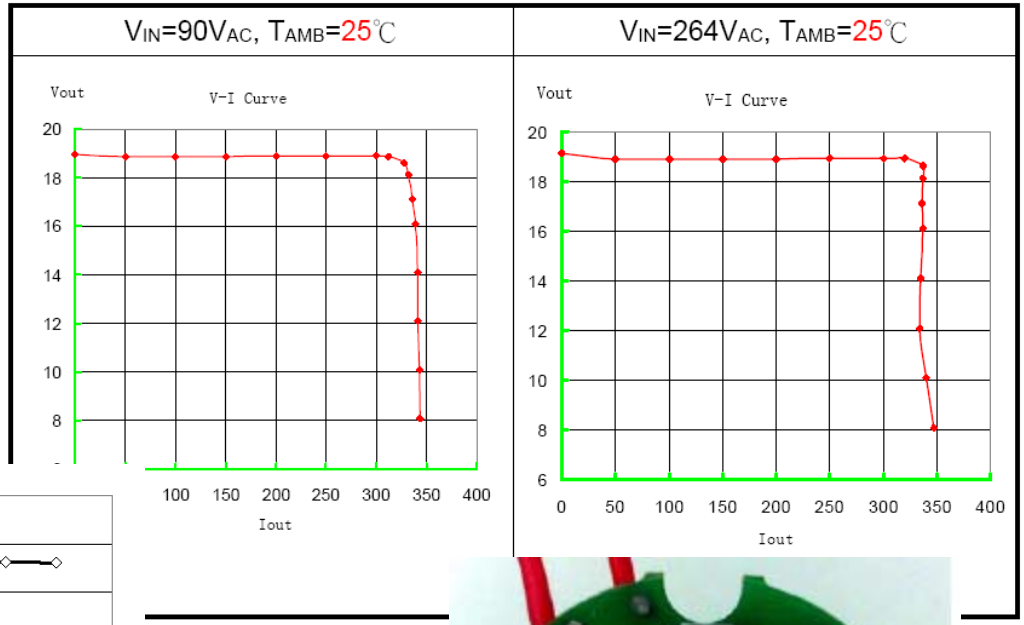


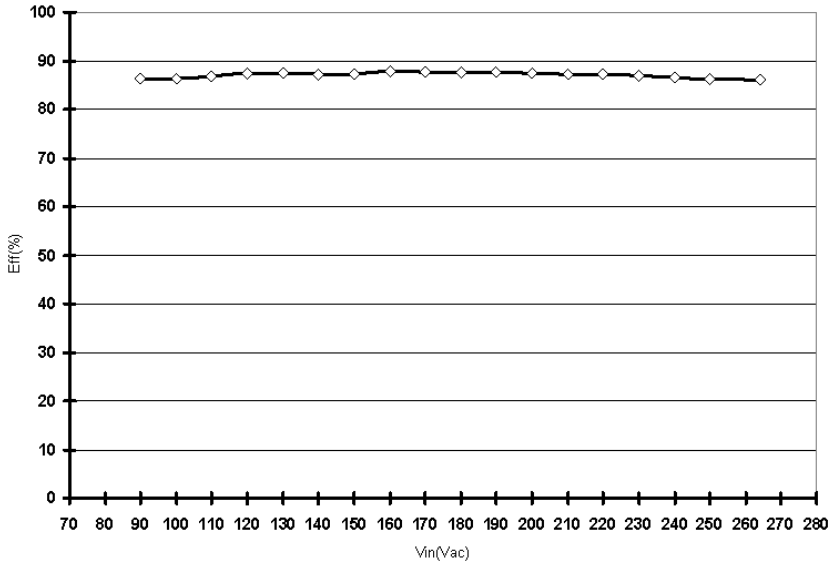
Example:
High Power LED Drivers 5-30W

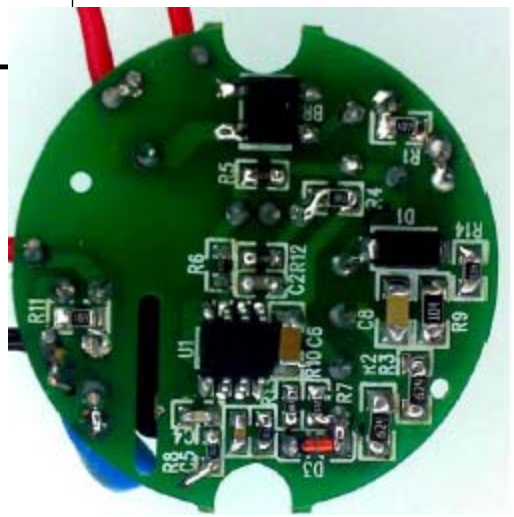


Measurements
Efficiency and V-I curve

87% efficiency 24V@870mA







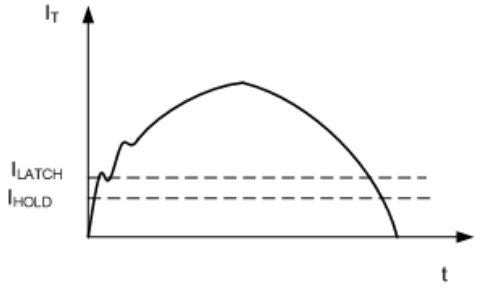
Challenges For Dimmable LED Driver Requirements

- ✓ The first challenge is to replace the socket of A-lamps with LED lamp, while maintaining **compatibility with existing dimmers**.
- ✓ Existing wall dimmers are designed to drive purely resistance A-lamp loads. When it drives a capacitive load or current source, the dimmer may not work properly.

- ❑ LED lamp needs to operate with different dimmer types:
  - ❑ Leading-edge dimmers, Trailing-edge dimmers, Smart Dimmers
  - ❑ In case the LED lamp can not work properly with certain dimmers, the LED lamps should provide certain safety protections to prevent fire, high leakage current etc.
- ❑ Dimming Performance
  - ❑ Wide dimming range 1% to 100%
  - ❑ No visible Flicker
- ❑ AC-cycle inrush current
- ❑ High Power Factor at maximum dimming level
  - ❑ Residential > 0.7
  - ❑ Commercial > 0.9

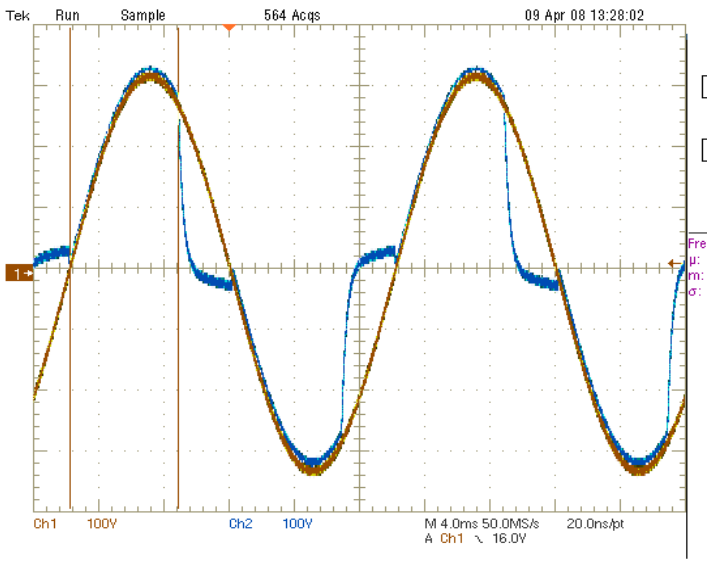
Knowing Wall Dimmers

- Dimmer types:
  - Leading-edge
  - Trailing-edge
  - Smart dimmers, adaptive adjust the turn-on angle to minimum the line distortion; could be leading-edge, could be trailing-edge
  - More..
- Dimmer impedance and power level also varies
  - R
  - R-L
  - R-C
  - 400W, 600W etc



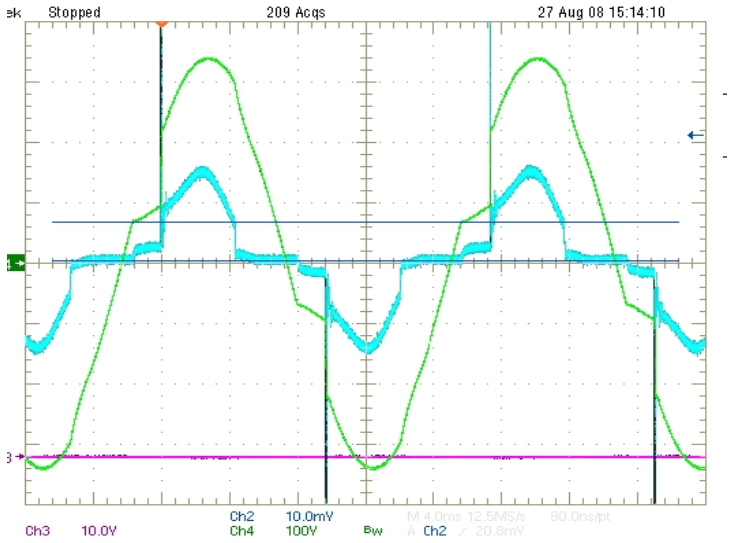
- Dimmer with Triac
  - The gate current must remain present until the load current has reached the latch current (IL) and then the triac will remain on until the load current falls below the hold current (IH).
  - This requirement creates the issue for switch-mode power supply where the impedance is not purely resistive (reactive load = current not in phase with voltage).

Knowing Wall Dimmers



Trailing edge dimmer

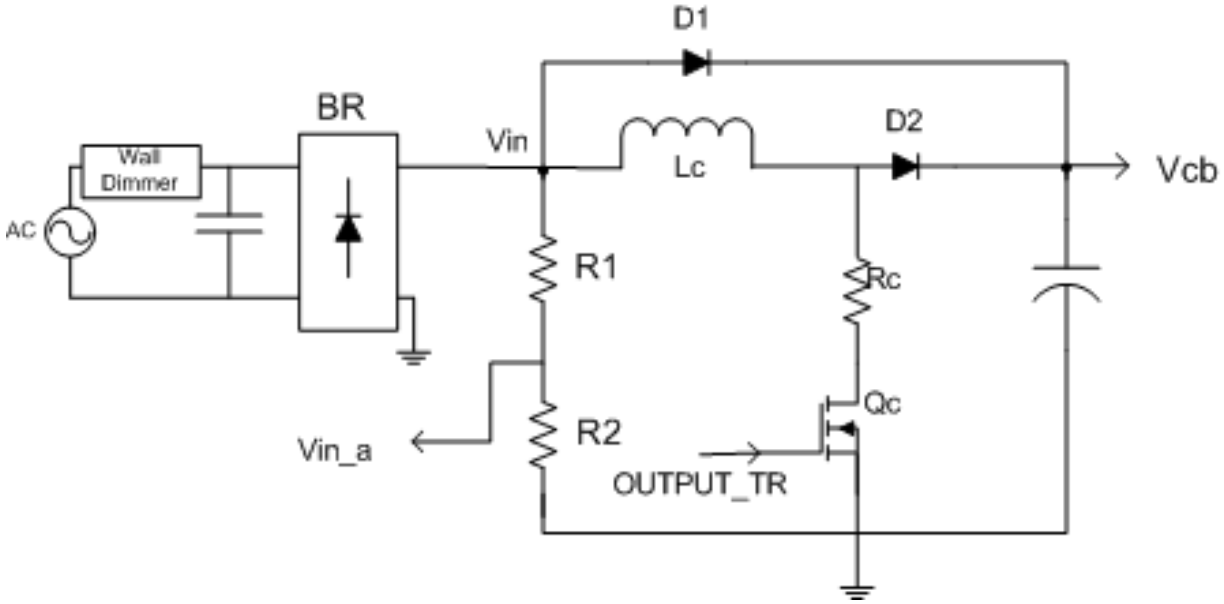
When trailing edge dimmer works with low power LED driver, it is difficult to detect the falling edge.



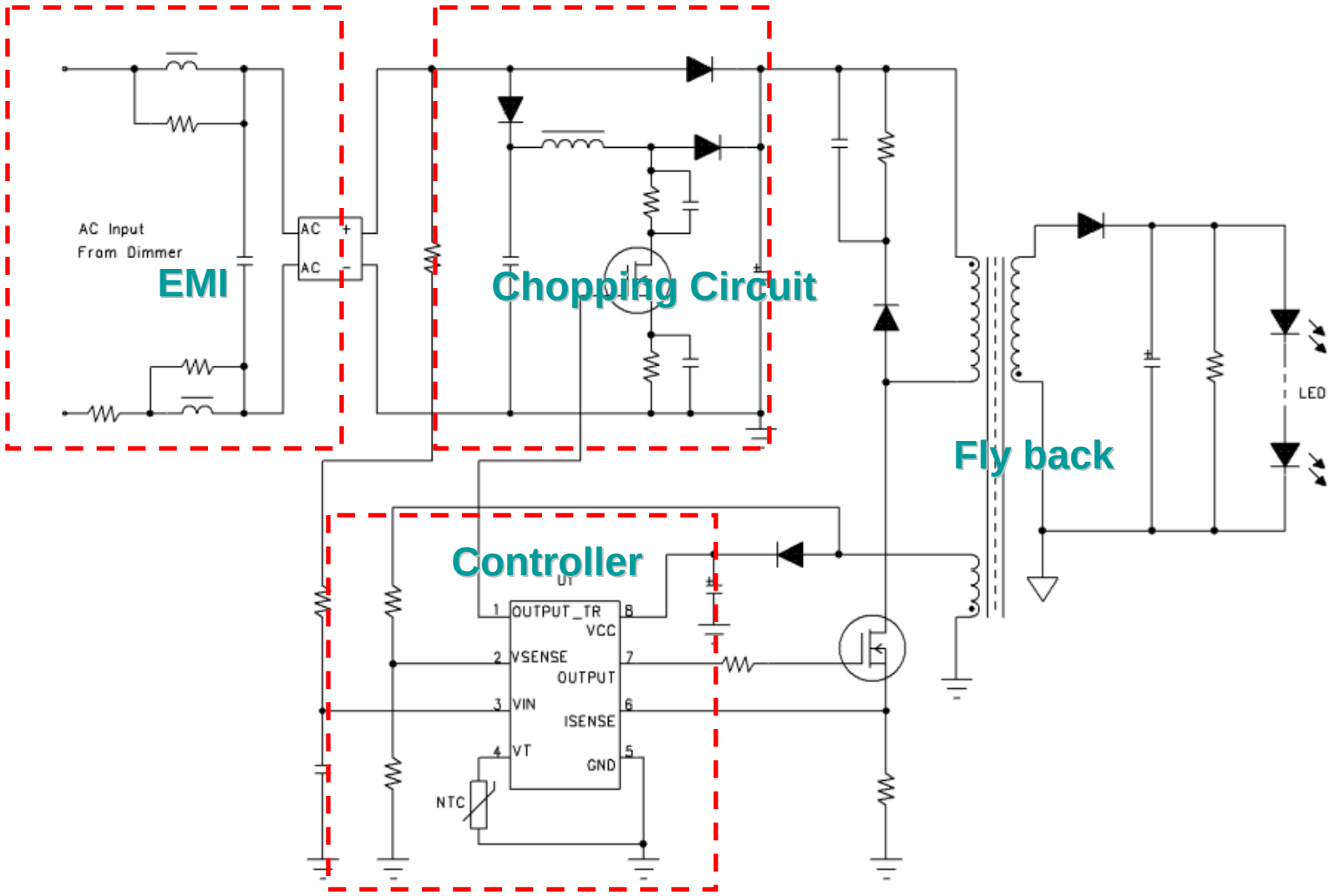
Leading edge dimmer

The TRIAC has a minimum gate trigger current (IGT) to turn the TRIAC on. It also requires a minimum holding current to hold the TRIAC on once conducting. When the current drops below the holding current, the TRIAC turns off.

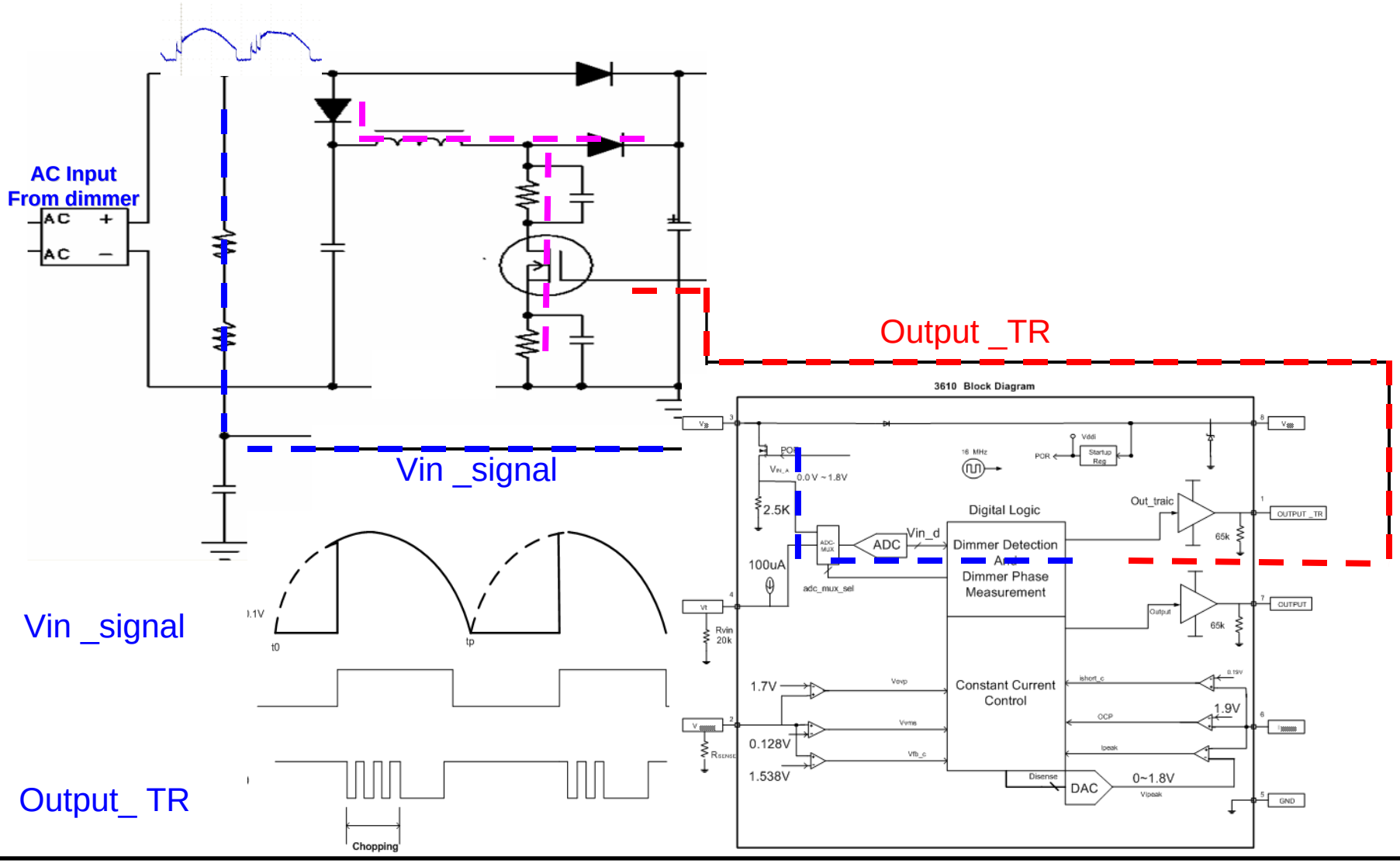
- Unique Method to Configure the Dimmer Type
- Provide the Pure resistive impedance to Wall Dimmer
- Line current shape to improve power factor
- Reduce AC-cycle Inrush current



Overview iW3610 Simplified Schematic

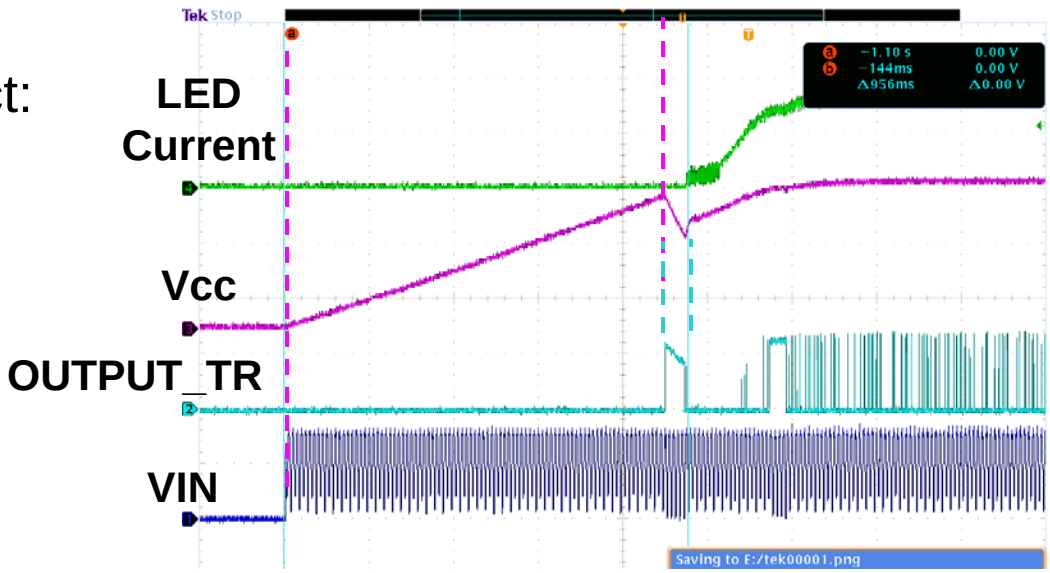


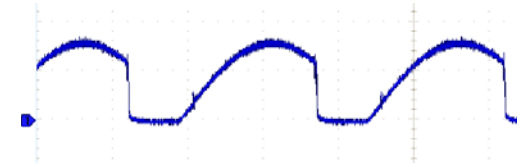
Chopping Control Scheme



Dimming Detection

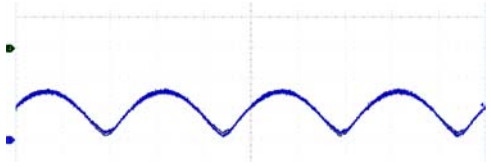
- Smart Dimmer Detection
  - At configuration state, Detect:
    - Leading-edge
    - Trailing-edge
    - No-dimmer



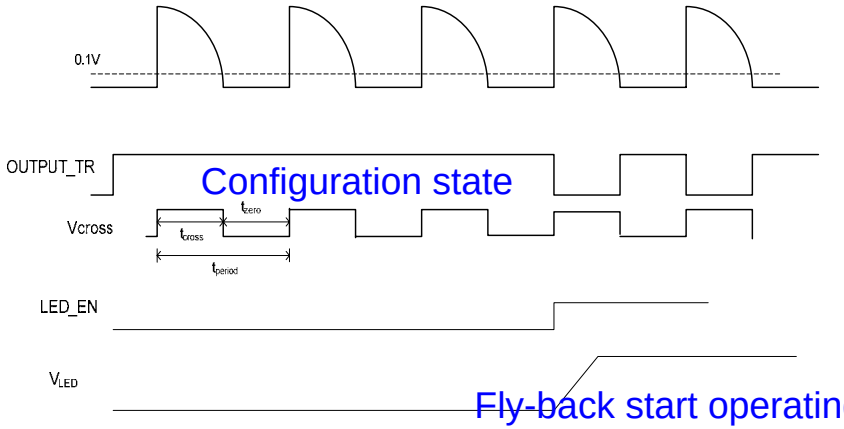


Trailing-edge

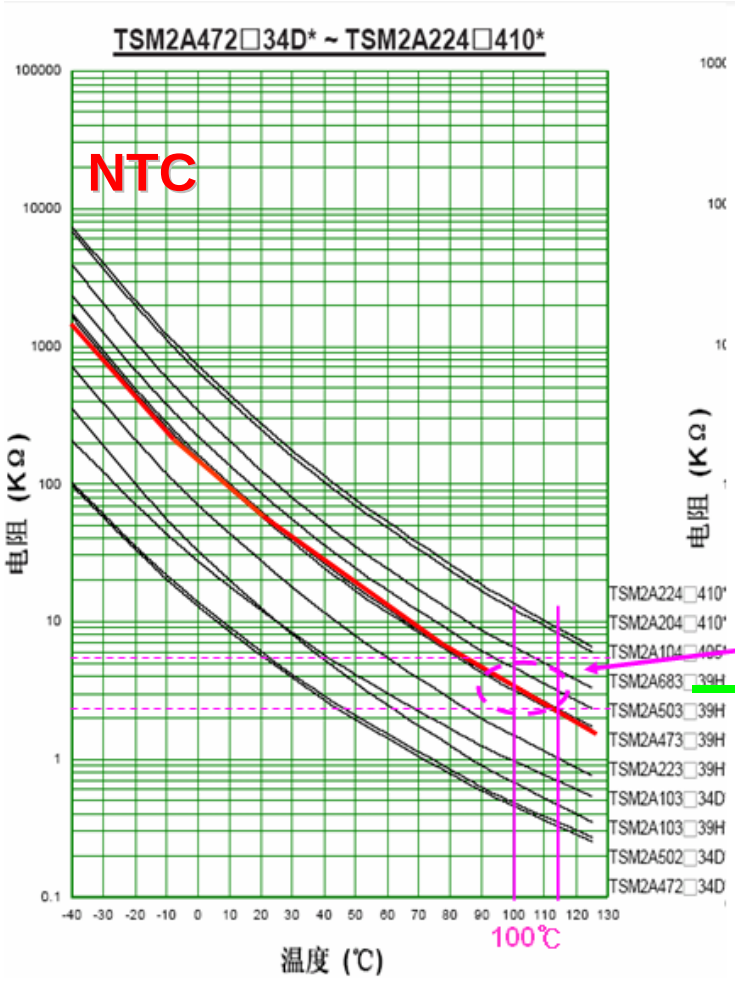
Leading-edge

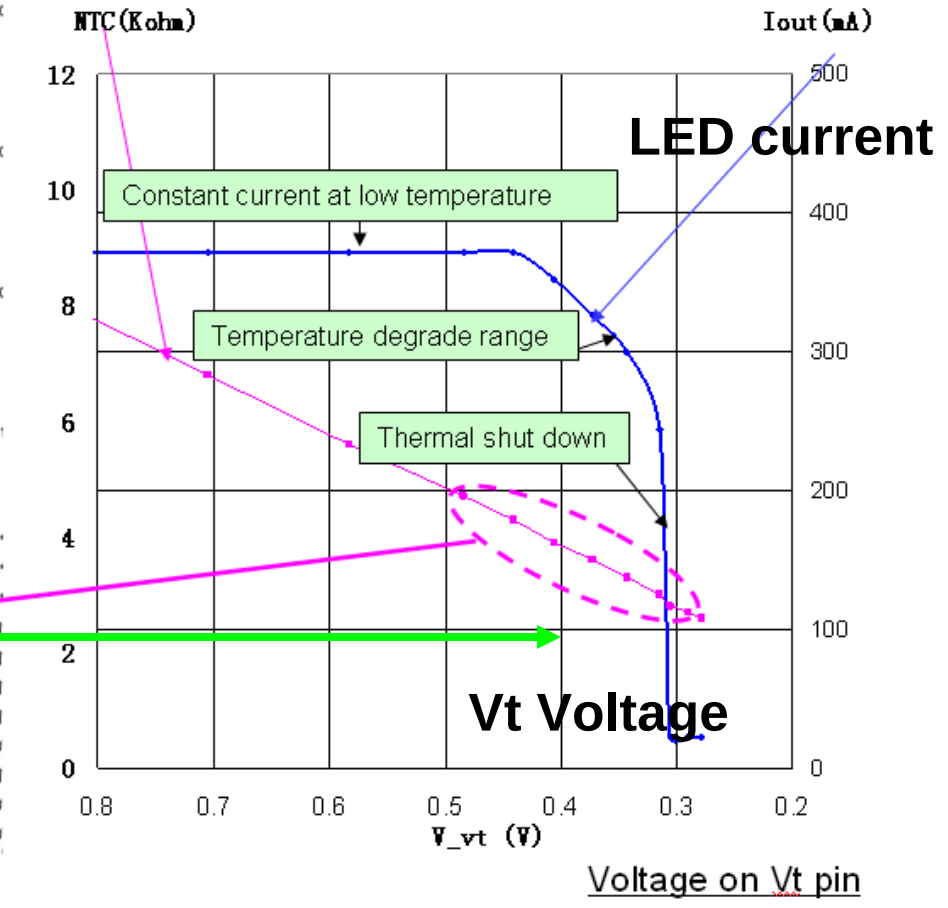


No-dimmer

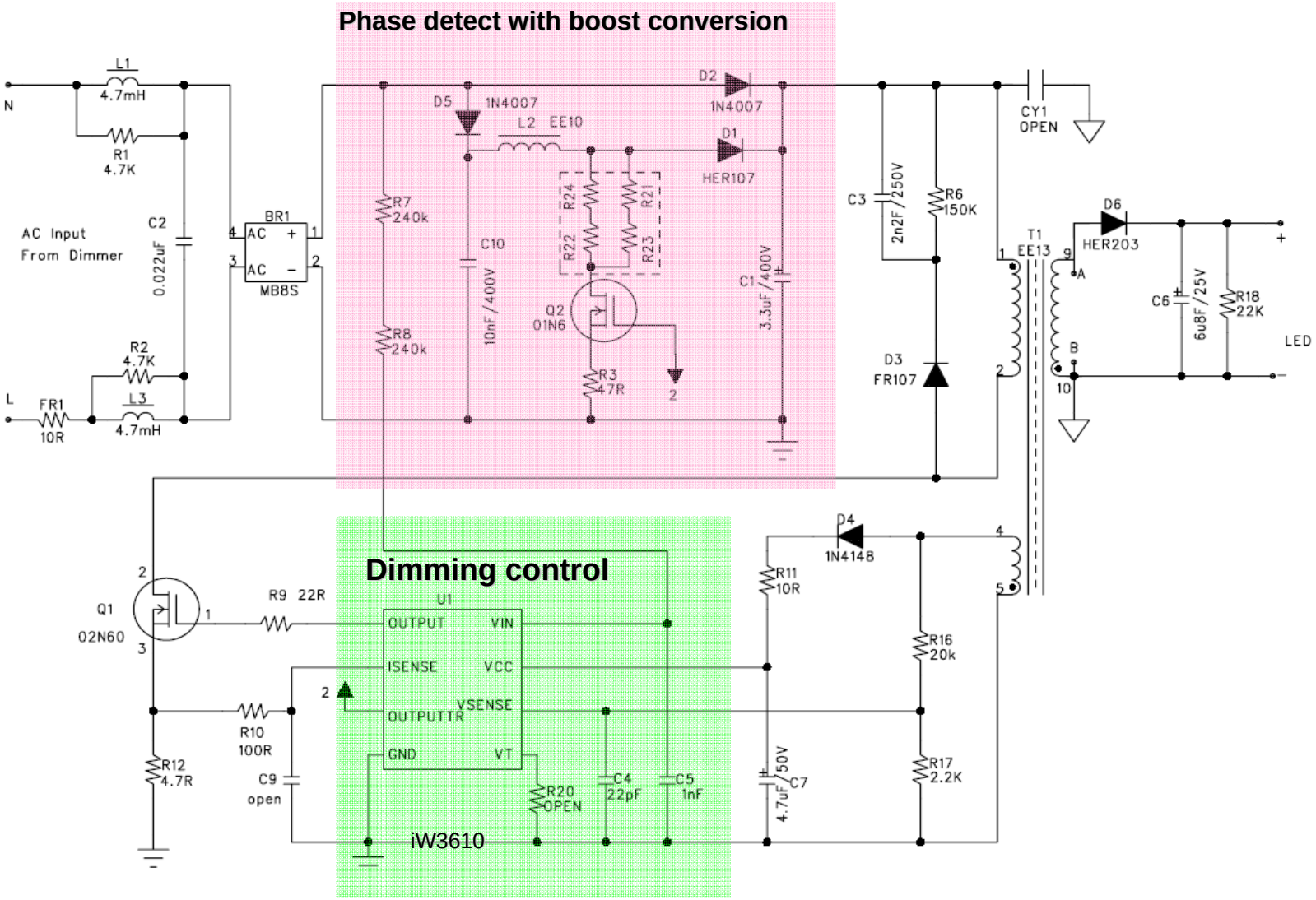


Thermal
Drifting and Protection

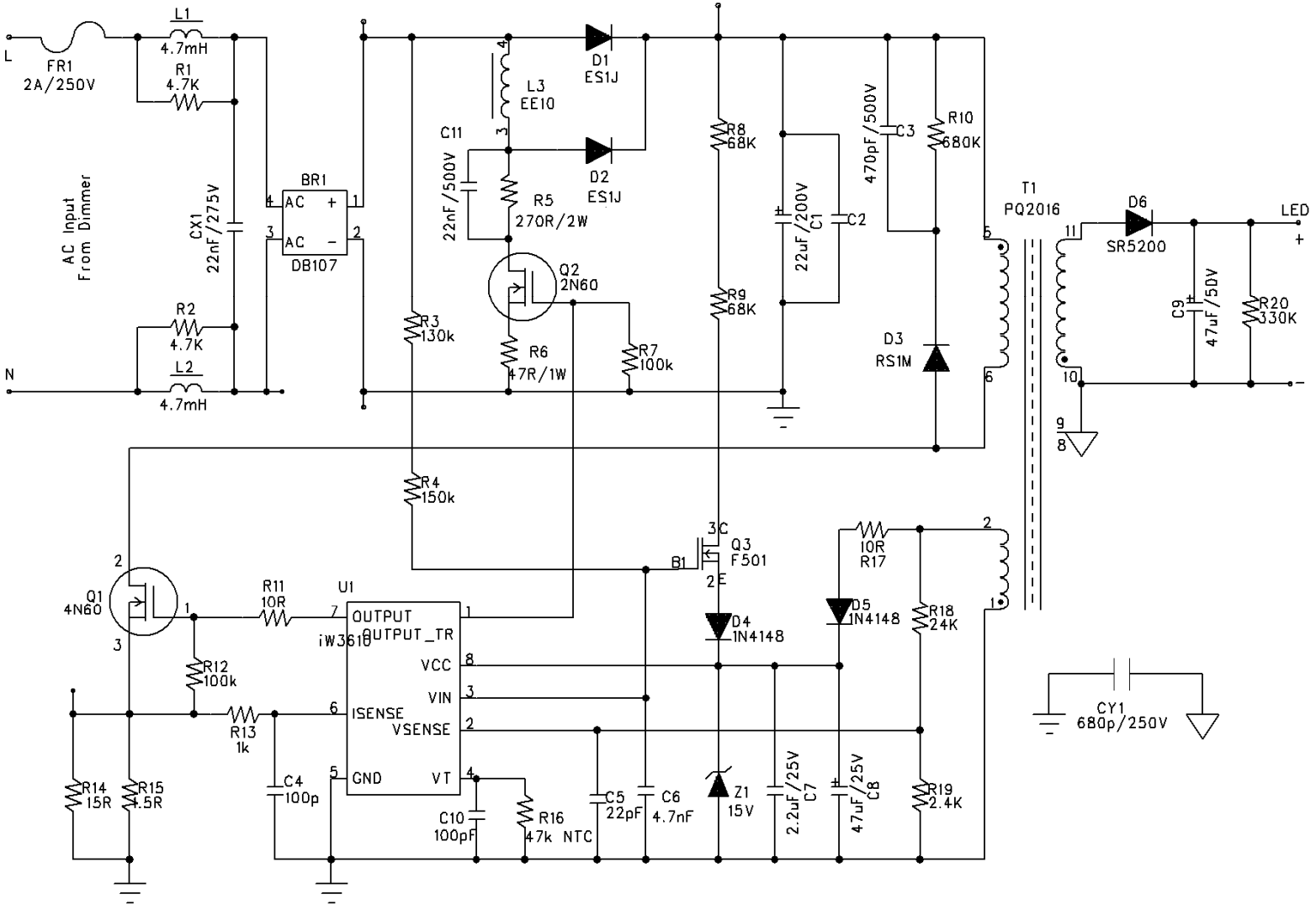




Example:
5W Dimmable LED Lamp



Example:
17W Dimmable LED Lamp



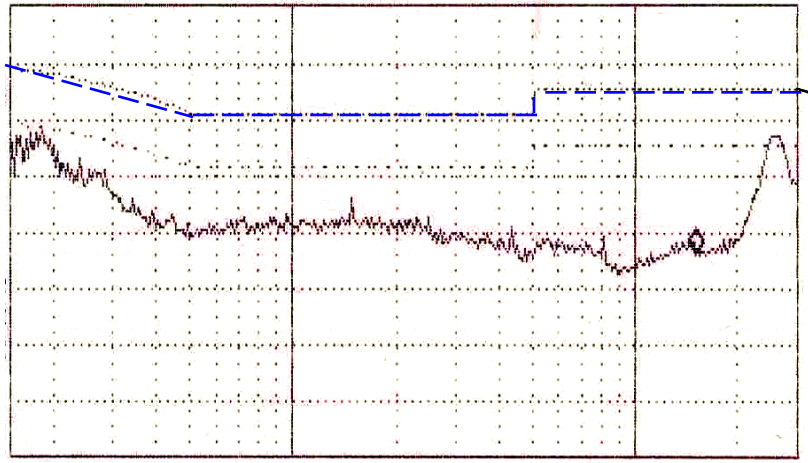
Measurements:
Efficiency Regulations

# of LEDs	Vin (V)	Pin (W)	Vout (V)	Iout (A)	efficiency	PF
7LEDs	85	16.82	26.53	0.515	81.23%	0.70
	90	16.69	26.53	0.515	81.88%	0.69
	100	16.53	26.54	0.515	82.68%	0.70
	110	16.24	26.54	0.515	84.17%	0.72
	120	16.03	26.54	0.515	85.27%	0.71
	130	15.95	26.54	0.515	85.69%	0.69
	135	15.83	26.55	0.515	86.36%	0.64

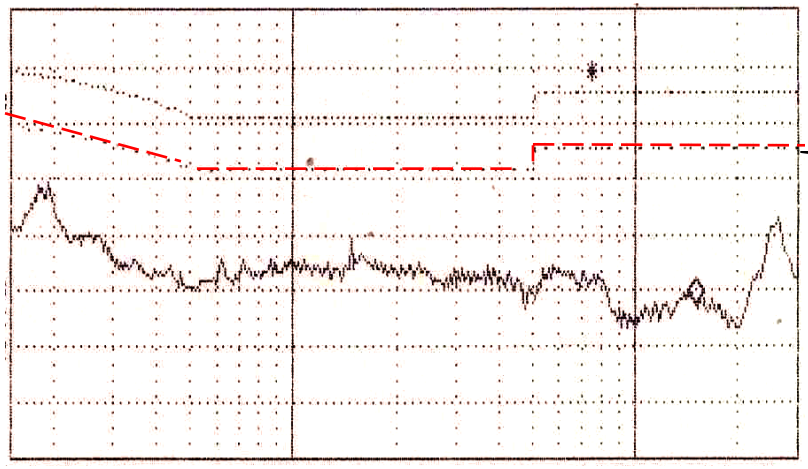
Conducted EMI Result

120V_{AC}/60Hz

PKScan



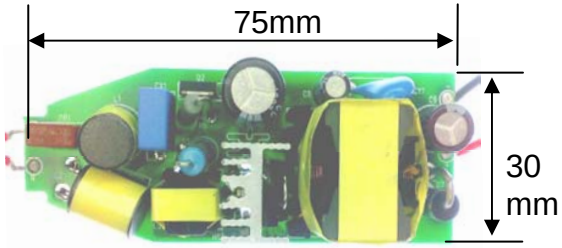
AVScan

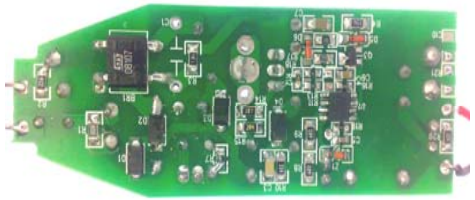


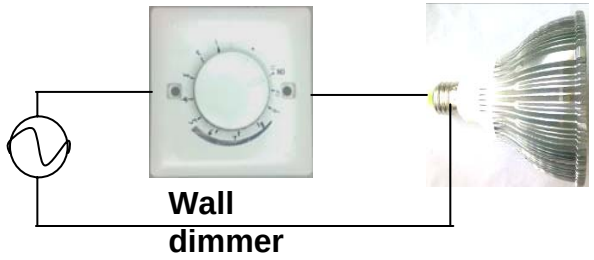
Test Conditions :
LED Full load. Output Ungrounded.

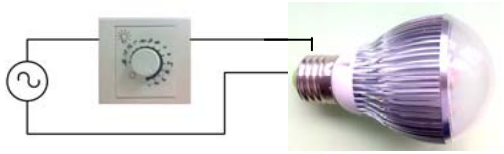
Full Dimmable LED Lighting Solution with Wall Dimmers

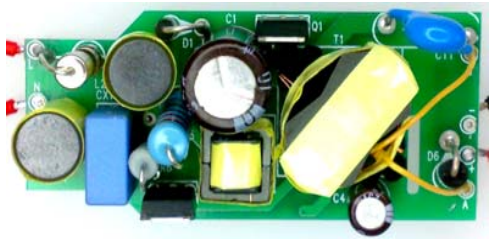
DESIGNING WITH LEDs
EDN design
FULL-DAY TECHNICAL SEMINAR AND WORKSHOP

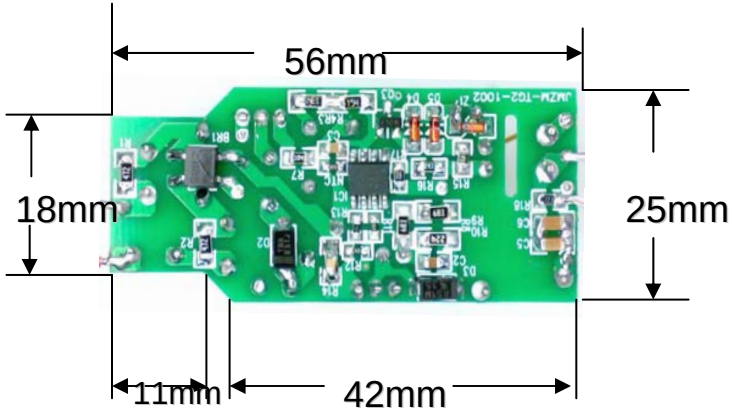






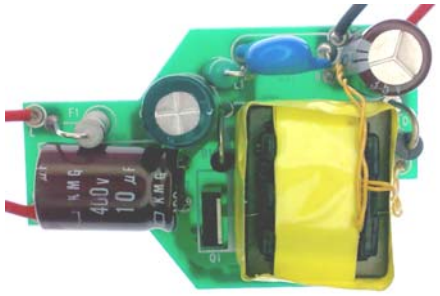


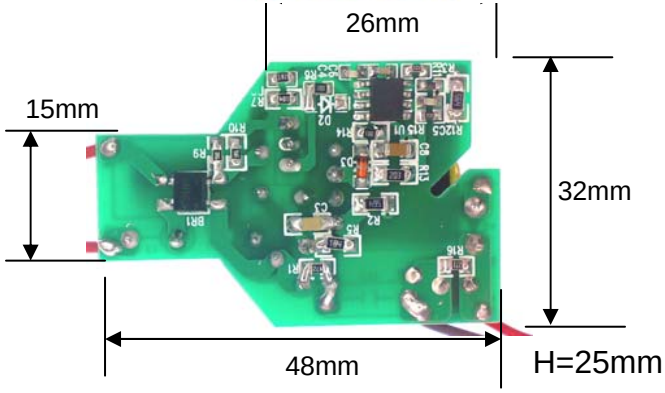


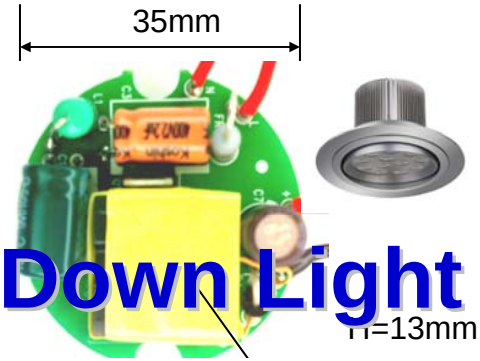


Complete Solutions for Indoor General Lighting

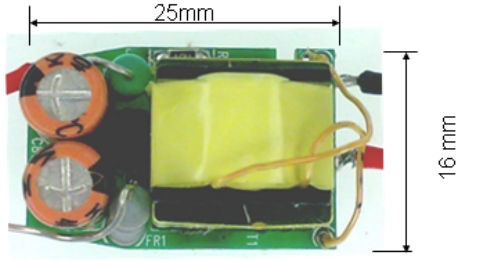
DESIGNING WITH LEDs
EDN design
FULL-DAY TECHNICAL SEMINAR AND WORKSHOP



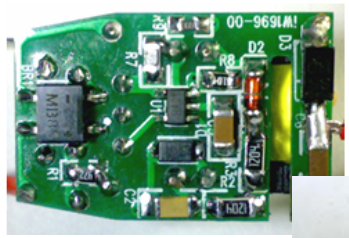


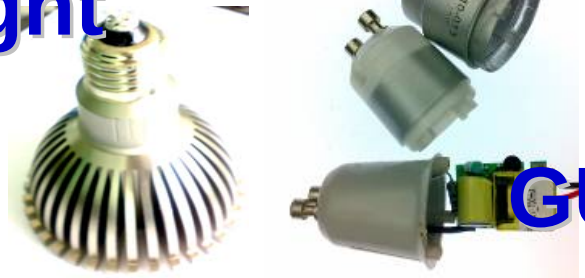


Down Light



PAR Light





GU10 MR16

Complete Solutions for T8 /T12

DESIGNING WITH LEDs
EDN design
FULL-DAY TECHNICAL SEMINAR AND WORKSHOP

- 15W, 18W, 20W
- High efficiency > 85%
- Power factor > 0.9

L x W x H: 230 x 19 x 13 mm

Thanks

iWatt, your partner to deliver green power