LED Drivers for General Illumination

Presenter:

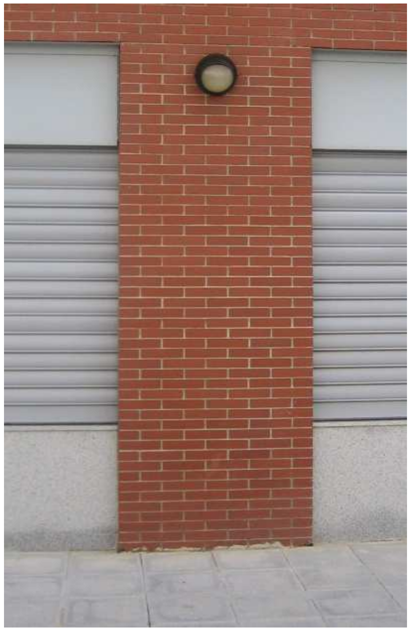
- Chris Richardson
- Systems Applications Engineer, Lighting
- Europe

Agenda

- What is “General Illumination”?
- 3 Pieces of the Puzzle
- Challenges in General Illumination
- Arraying your LEDs
  - All in series
  - Series-parallel
- AC to CC (Constant Current)
- DC Bus with Multiple DC-DC LED Drivers
  - Buck is Best
  - Boost for Long Strings
  - Buck-boost: when all else fails!

What General Illumination is:

Non-portable lighting, usually running from line power (AC mains)

Streetlighting	**Interior Lighting**	**Exterior Lighting**
		
High Power Wide Area	Emergency, Downlight	Accent

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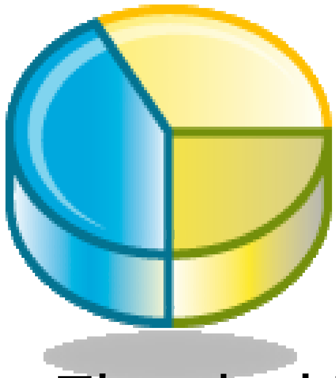
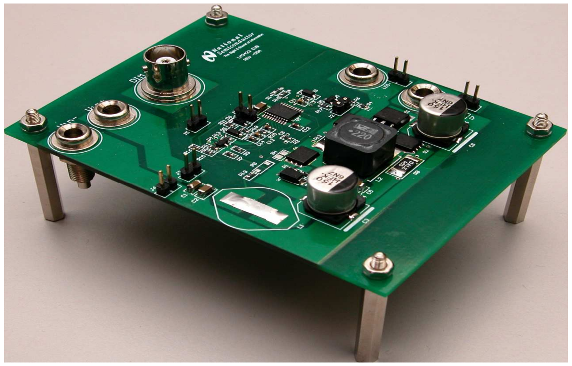
Three Pieces of the Puzzle

•Thermal is critical. Good designs integrate heat-sinking into the structure of the lamp



•Optical – also critical, must be integrated into the mechanical design of the lamp

•Electrical Drive: often an afterthought (like most power supplies)



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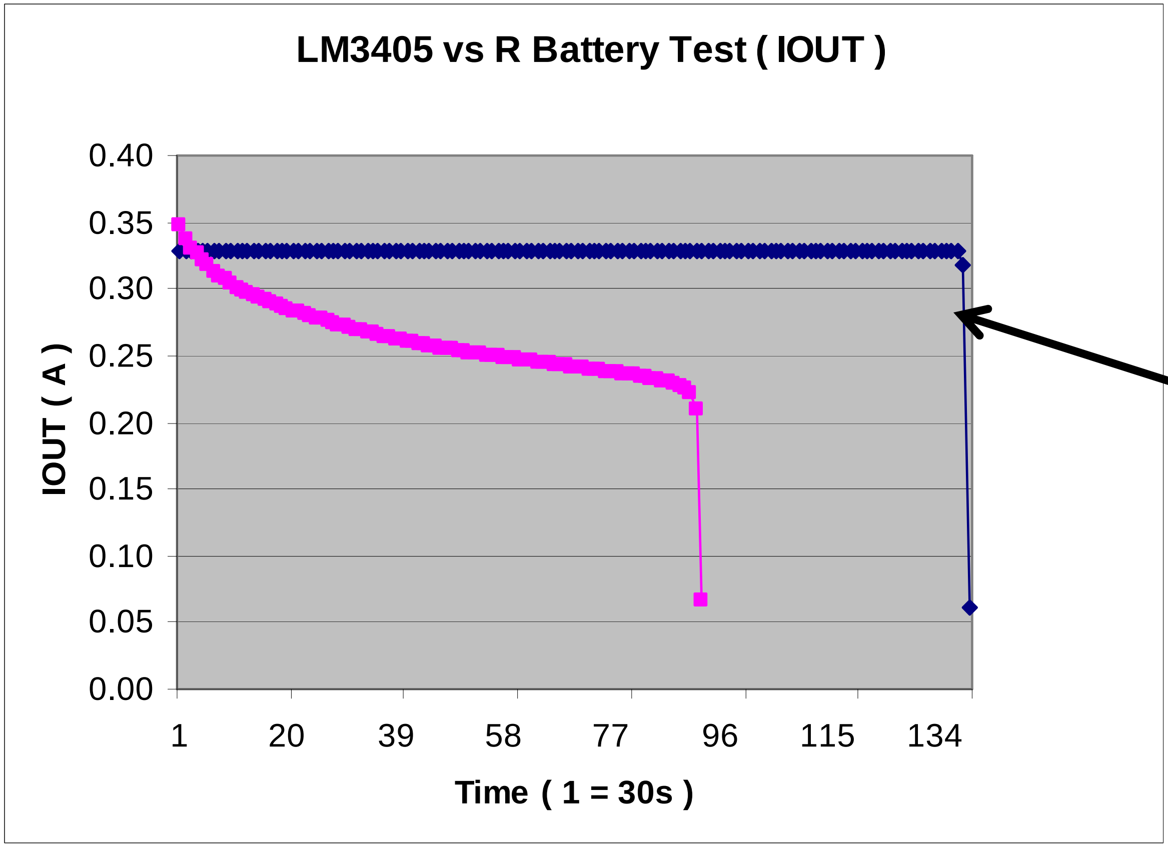
Why use a Driver?

- Why not a resistor?



- Drivers are regulated power supplies
- Output current is regulated
- Output Power can also be regulated
- Switching regulators get the most from the battery!

BLUE = LM3405 LED Driver **PURPLE = Series Resistor**

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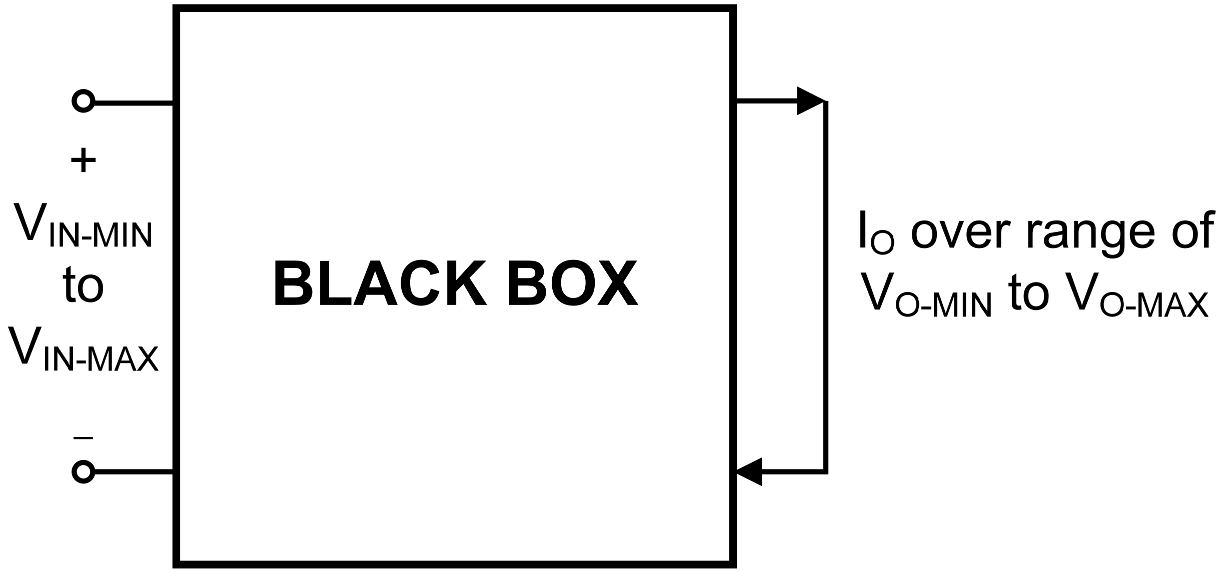
Challenges of General Illumination with LEDs

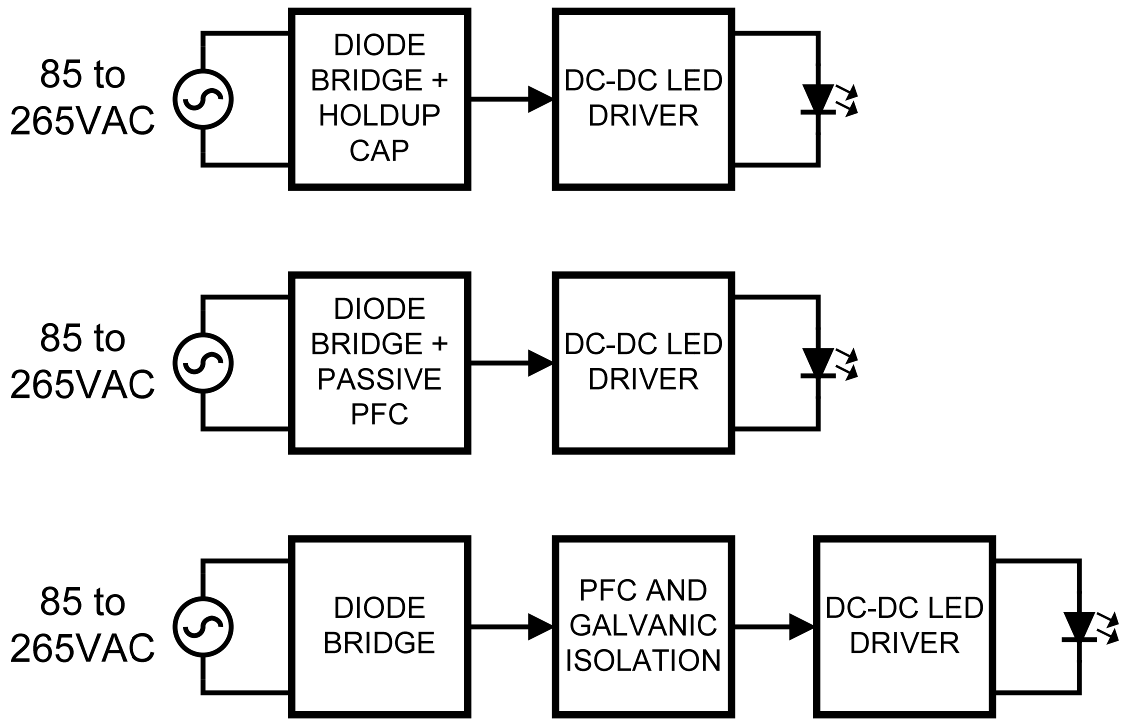
Many Opportunities, Few Standards

- LED lighting is too new and too varied for packaged "black box" drivers
- 10 different applications will use 10 different types of LEDs and/or 10 different configurations of LEDs
- 10 different LED driver designs are needed (at least!)



How Many Paths from AC to CC?

- **Direct non-isolated from AC to LED**
  - **Some 'black box' solutions, but range of V_O and I_F is limited**
  - **Safety and code/legal issues without isolation**
- **Multiple-stage AC to LED with isolation, PFC**
  - **Also some 'brick' type solutions. Still not very flexible**
- **Intermediate DC bus voltage and DC-DC LED drivers**
  - **Most flexible but most expensive: DC bus voltage determines topology of LED driver**



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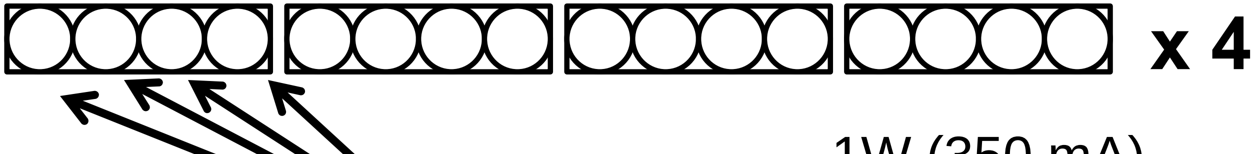
Once the LEDs Have Been Selected

- Lighting designers know how many lumens they want
- They know the color temperature or the wavelength needed
- Ex. City streetlight, uses total 64 LEDs
  - Input is 110VAC: output is up to 200W depending on LED current
  - Needs high efficiency and high power factor
  - Replacement for metal halide or high-pressure sodium



1W (350 mA)

2W (700 mA)

3W (1000 mA)

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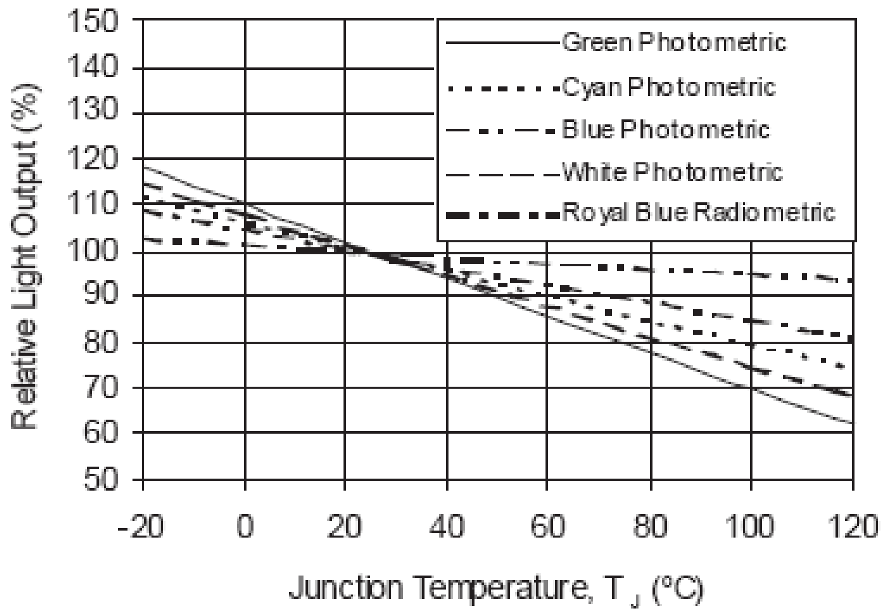
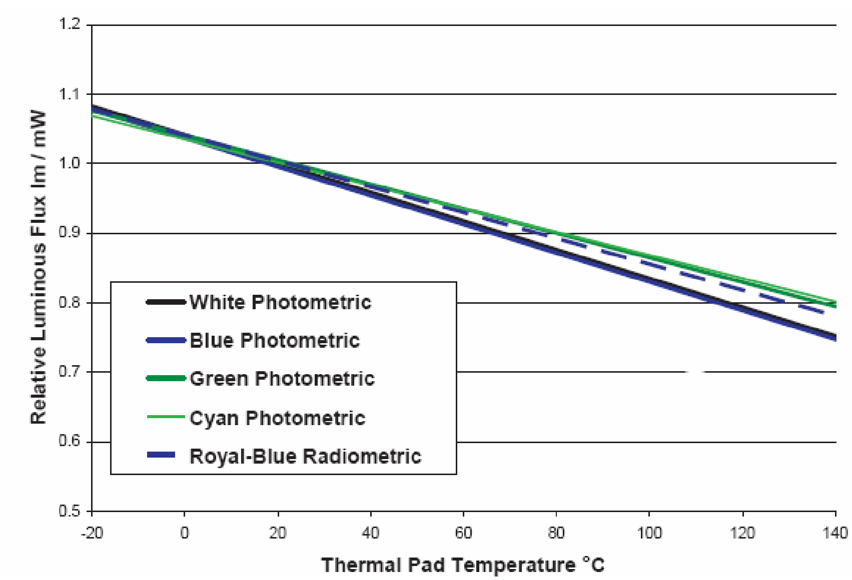
Arraying your LEDs

- **Today's typical 1W LED gives 50 lm/W at 25° C**
- **Then drops with rising T_J**

- **Today's best 1W LED approaches 100 lm/W at 25° C**
- **Then drops with rising T_J**





Most applications need more than one LED!

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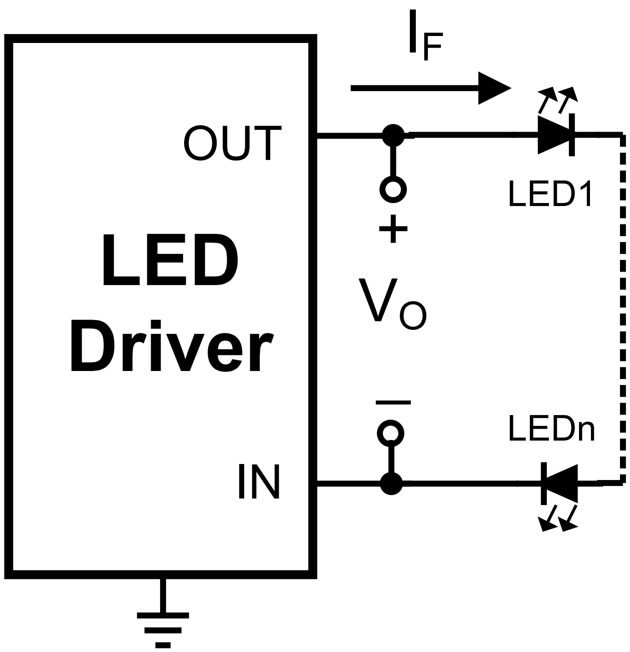
All In Series



- **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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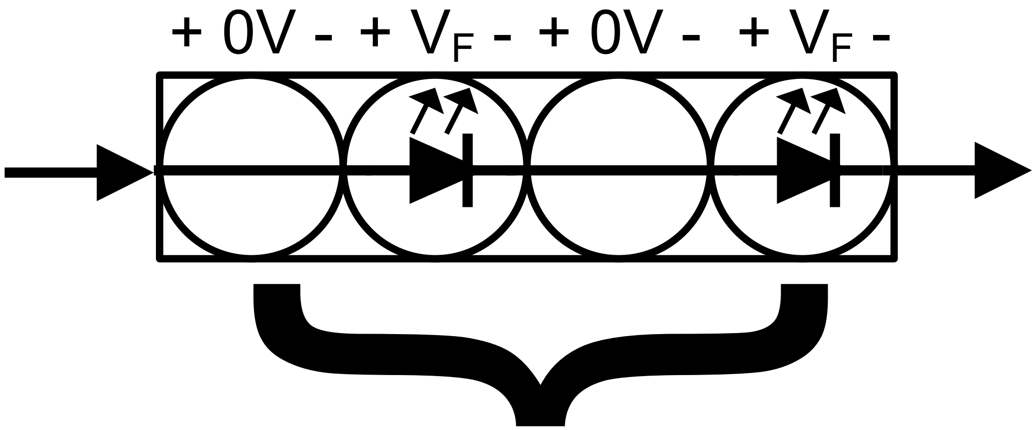
Short Circuit LED Failures in Series



- LED do fail short circuit (not as often)
- Voltage across short is usually near-zero
- Total output voltage decreases
- How many LEDs can fail before the lamp is considered 'dead'?

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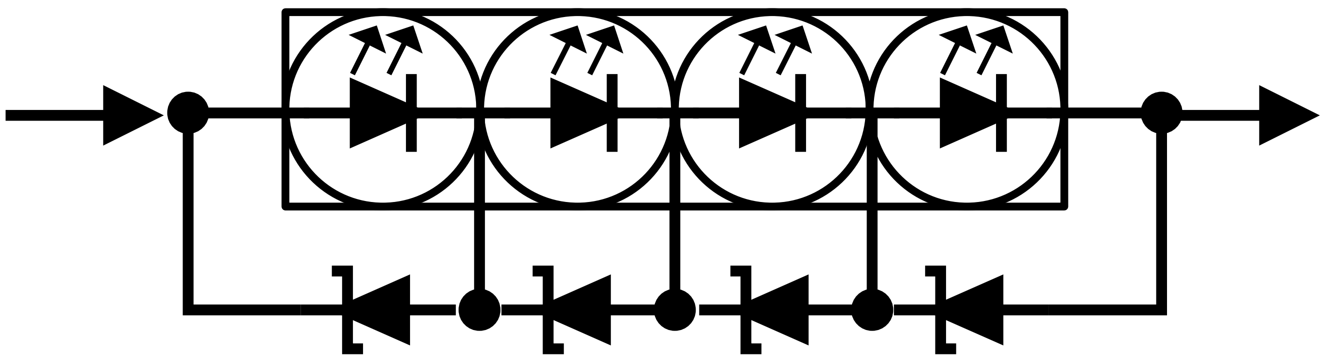
Open Circuit LED Failures in Series



- **Anti-parallel zener protection keeps the lamp lit when one LED fails open circuit**
- **Zener breakdown V_Z must be higher than $V_{F\text{-}MAX}$**
- **Zener must be fairly high power**
- **Again, how many LEDs can fail before the lamp is considered 'dead'?**

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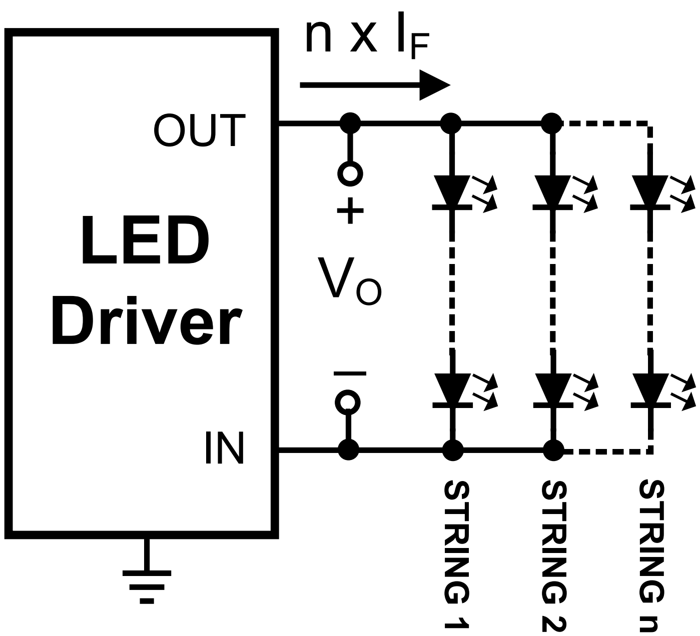
Series-Parallel



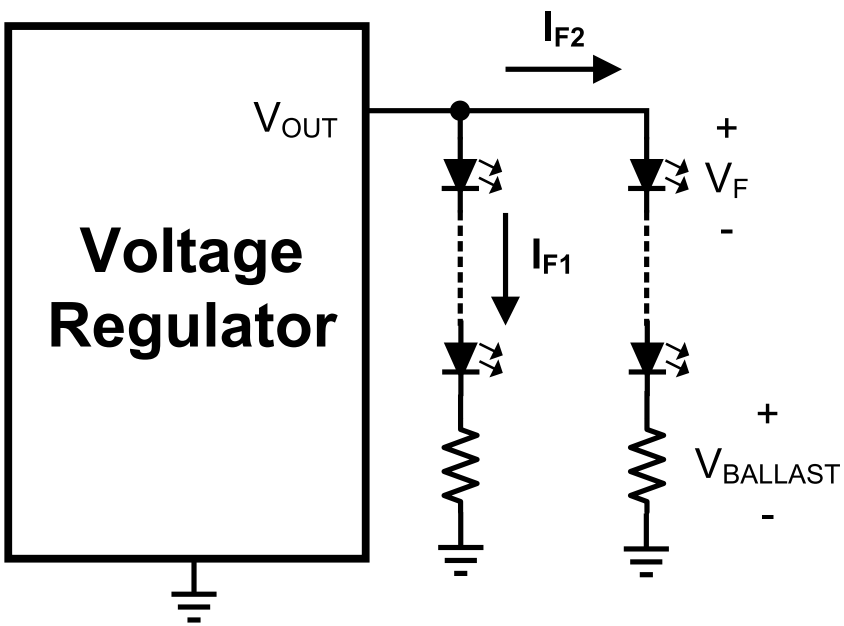
- **Pros:**
  - **Lower V_O**
    - **Staying within safety limits**
  - **Continues to operate if LEDs fail short circuit***

- **Cons:**
  - **No current matching**
    - **V_F varies from LEDs, even LEDs from same wafer**
    - **V_F drops with T_J, potential positive feedback loop**

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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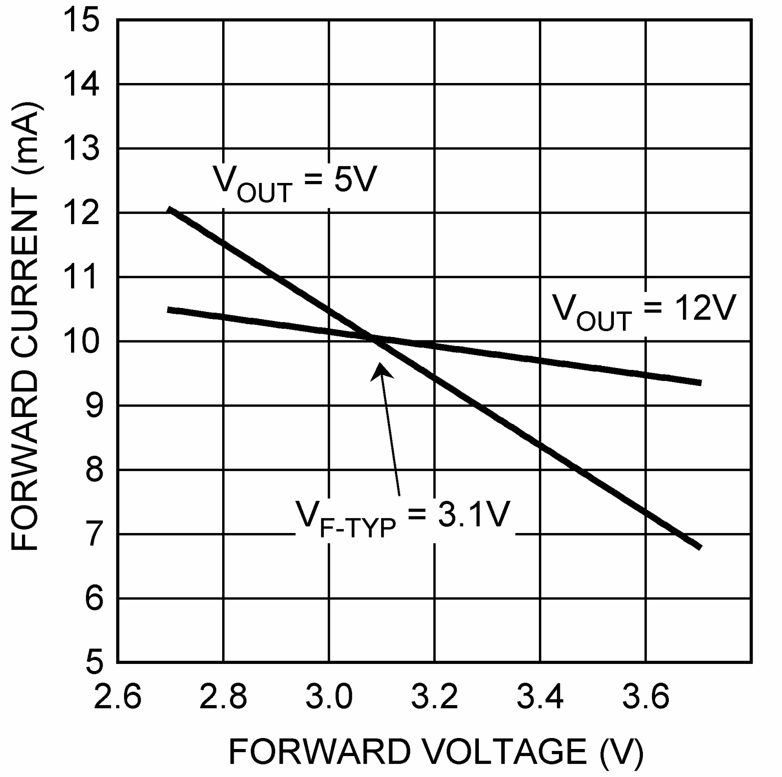
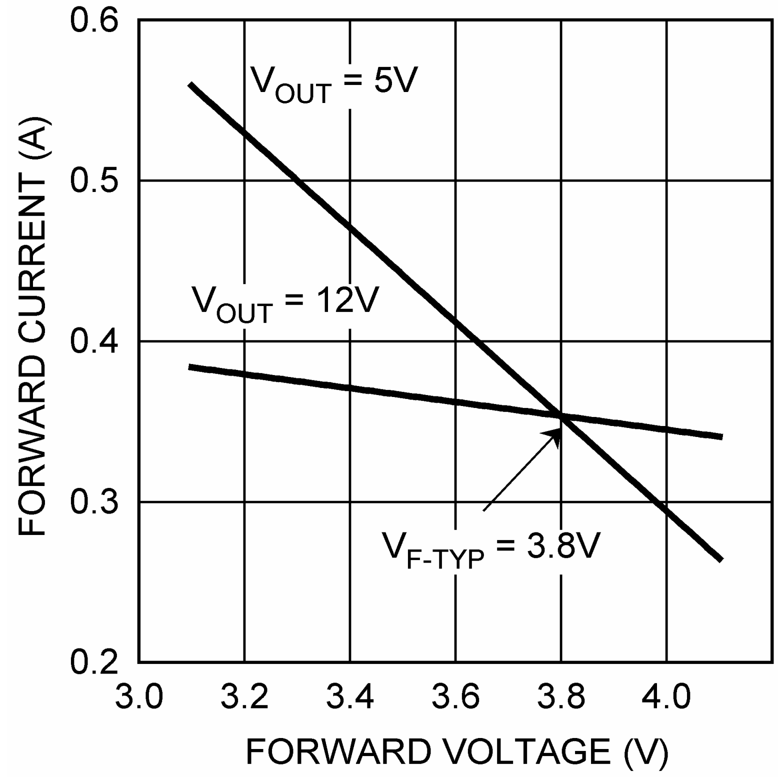
Pitfall of Series-Parallel #2

- **LED current accuracy drops at high current**
- **Dissipation in $R_{BALLAST}$ goes up quickly**



10 mA White LED



350 mA White LED

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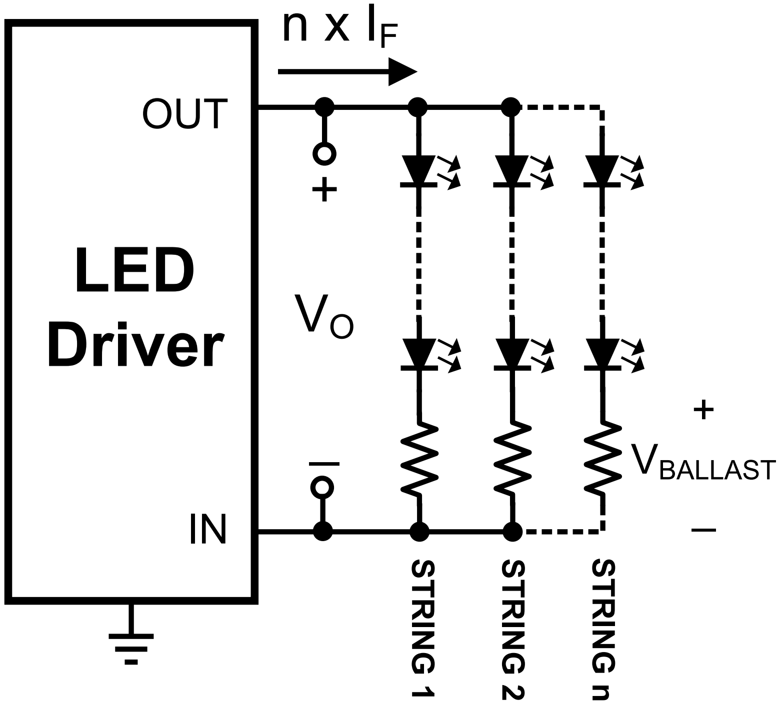
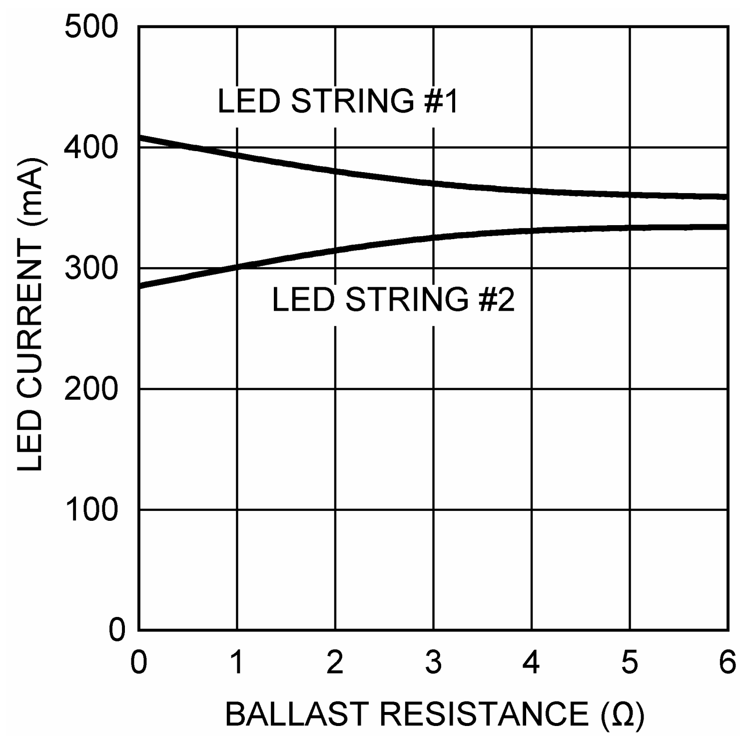
Pitfall of Series-Parallel #3

- Ballast resistors make a current source no better than a voltage source
- Ratio of dynamic resistance, r_D to $R_{BALLAST}$ determines the improvement in I_F matching





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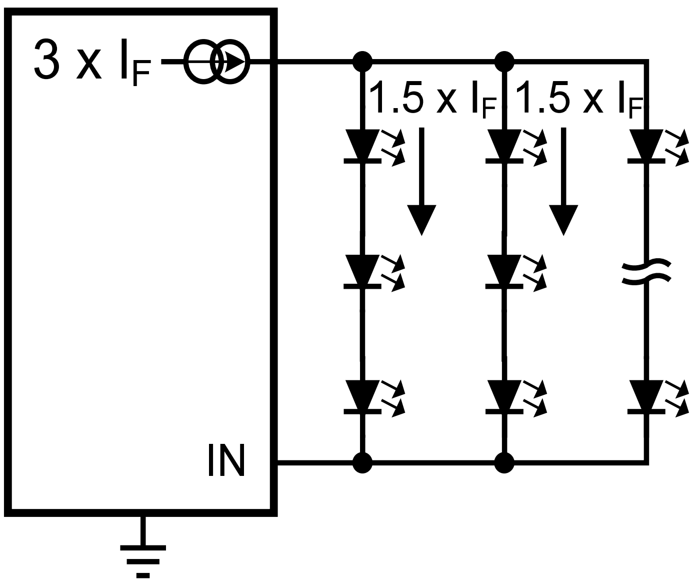
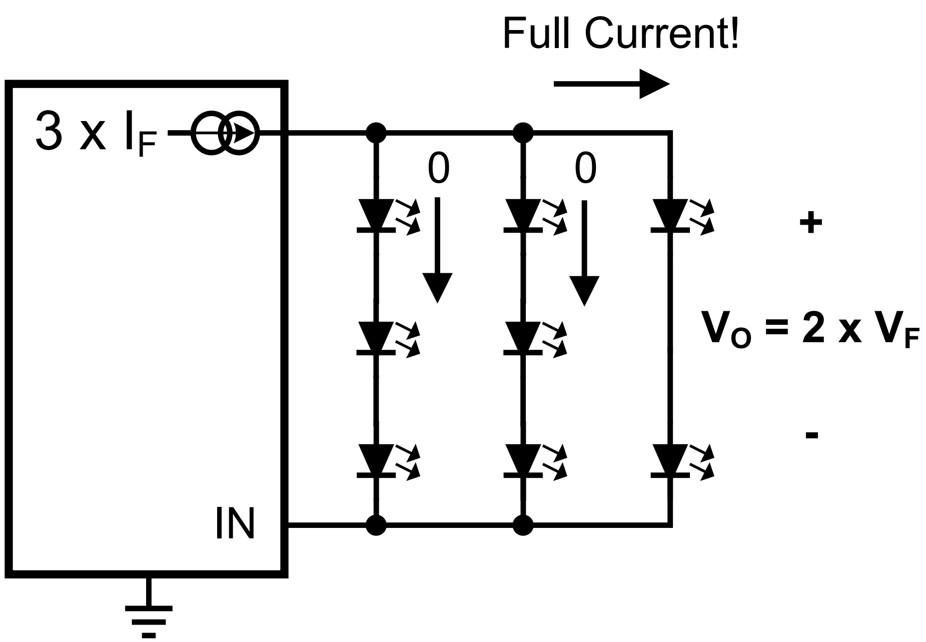
Poor Fault Response with Series-Parallel

- **Open Circuit**
- **Short Circuit**





- **This assumes that the LED driver is a pure current source**

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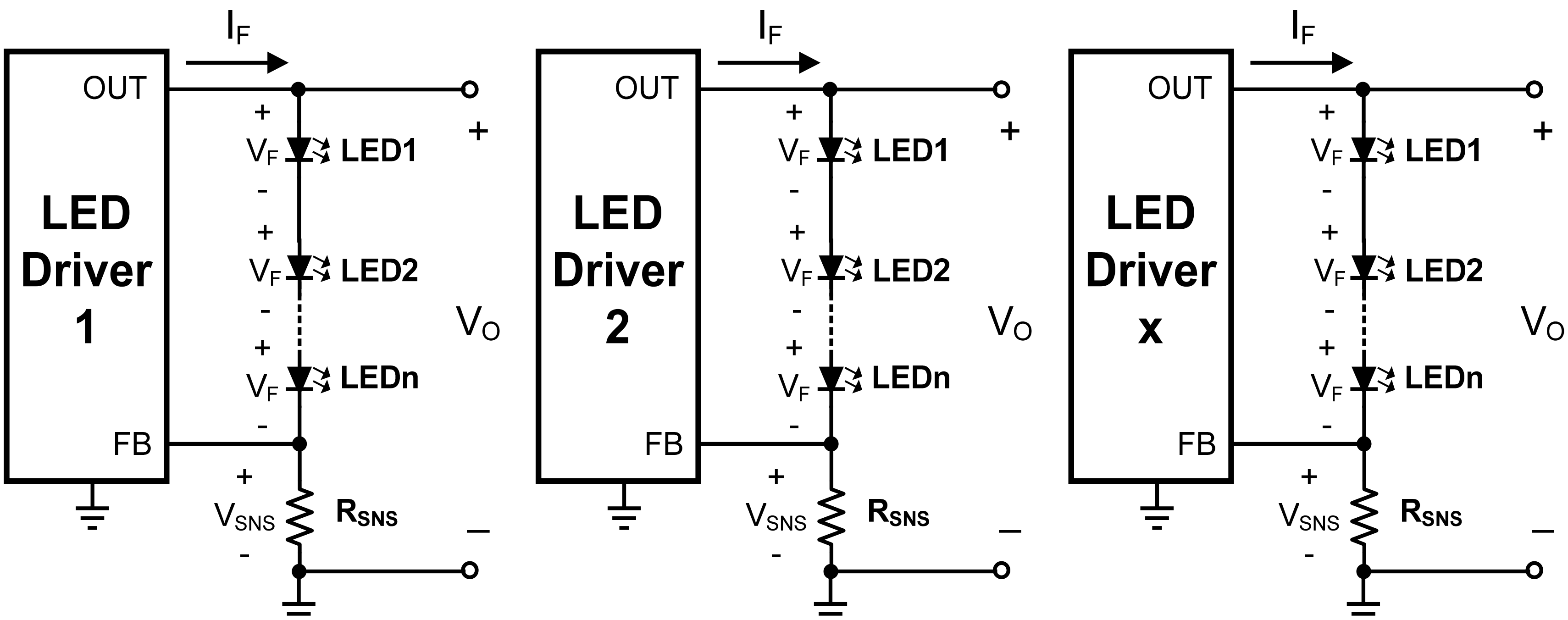
Multiple Regulators

- V_O can stay low for safety



- Best performance when an LED fails:
  - Open circuit: (1 – x) / x LEDs still operating
  - Short circuit: n * x -1 LEDs still operating*

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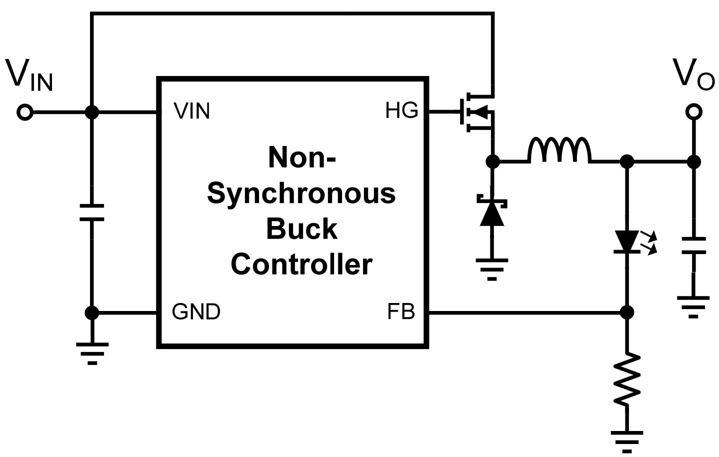
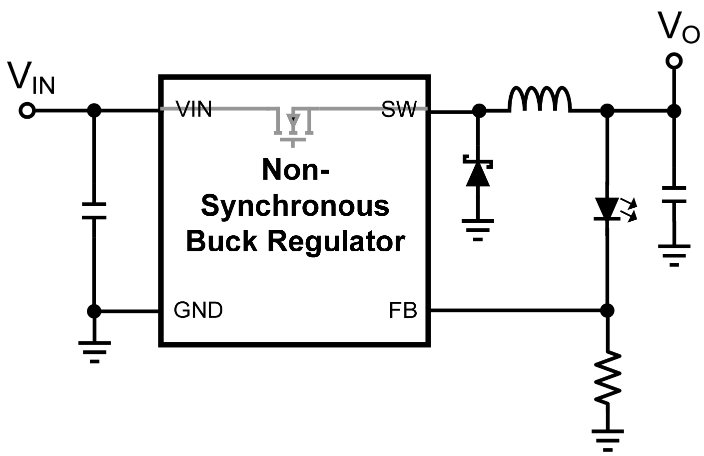
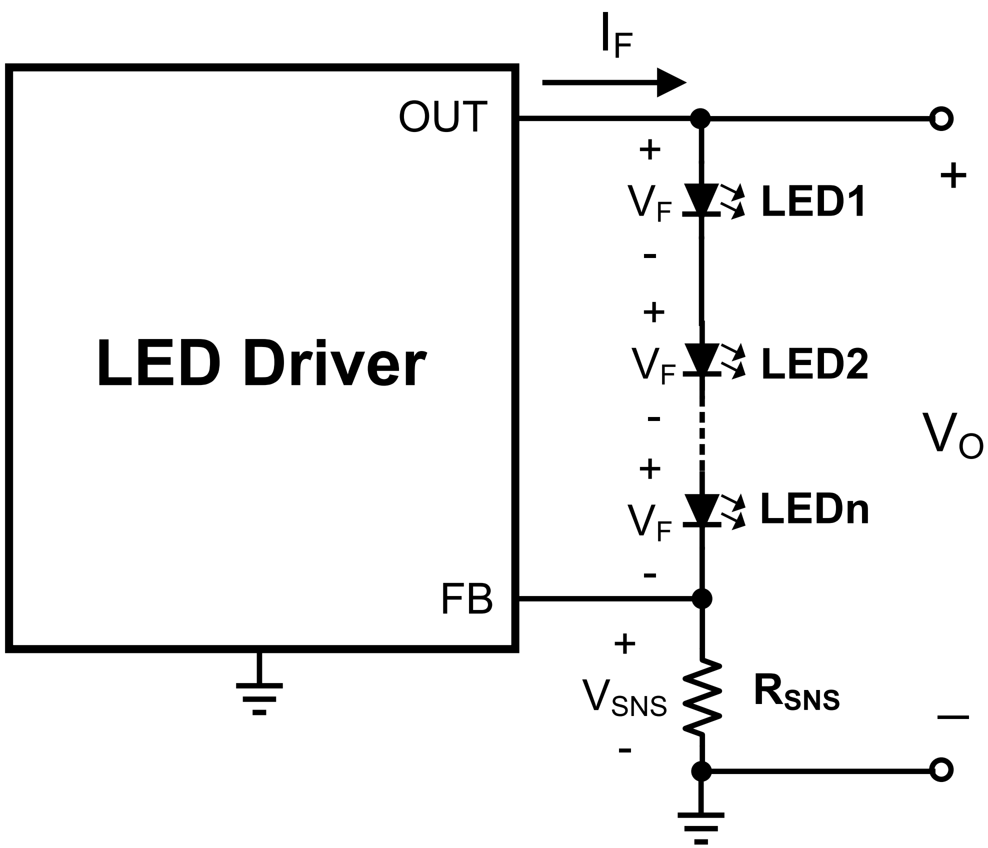
Determine the Total Output Current

- Linear Regulators are generally cost effective up to ~150 mA
- Switching Regulators (internal power switches) are generally cost effective up to 3A
- Switching Controllers (external power switches) are used above 3A





Control I_F, but know full V_O Range



Typical I_F Drive Currents:

-350 mA

-700 mA

-1000 mA

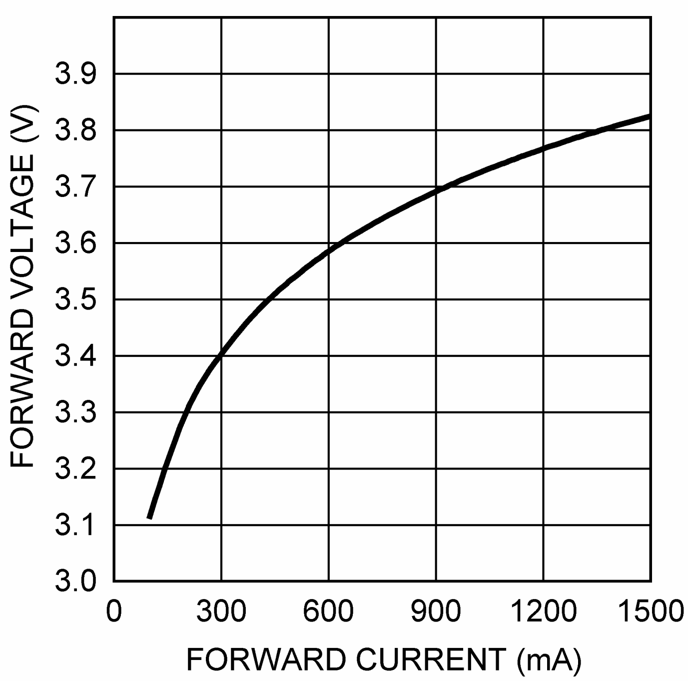
-1500 mA

-2A, 2.8A and increasing

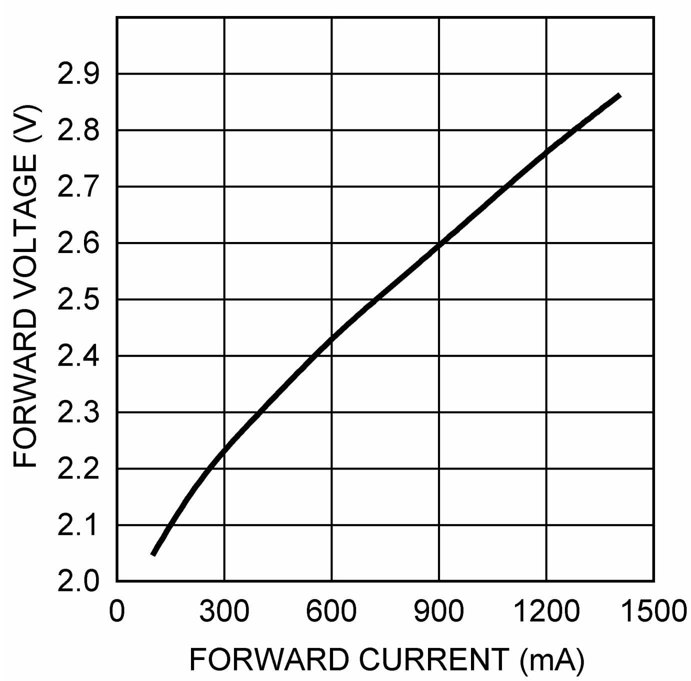
$$V_O = n \times V_F + V_{SNS}$$

LED Types by Chemistry and V_F

- **InGaN used in deep green, blue, and WHITE**
- **Forward voltage, V_F of 3V to 4V (typical)**



- **AlInGaP used in red, orange, amber**
- **Typical V_F is 2V to 3V**



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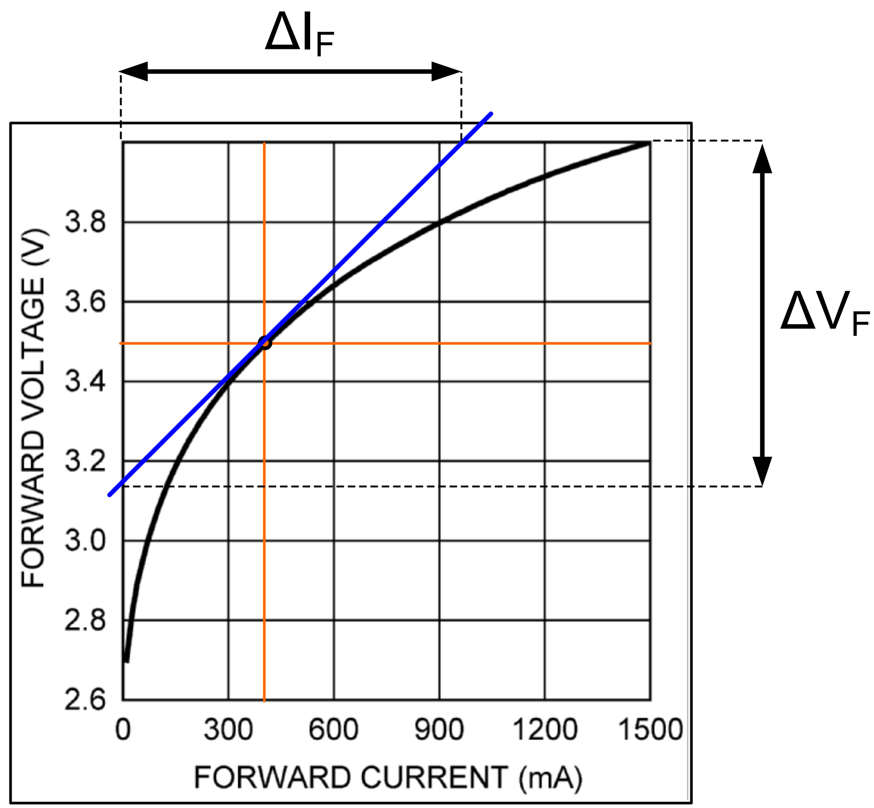
Dynamic Resistance as a Load

- Dynamic Resistance, r_D, is the inverse of the I_F vs. V_F curve
- r_D is typically 5x to 10x lower than the result of simply dividing $V_{F\text{-}TYP}$ by $I_{F\text{-}TYP}$
- The control loop sees r_D, so the load impedance $Z_L = r_D + R_{SNS}$
- Comparator-based regulators like hysteretic and constant on-time still use r_D to select the output filter capacitance



$$r_D = \Delta V_F / \Delta I_F$$

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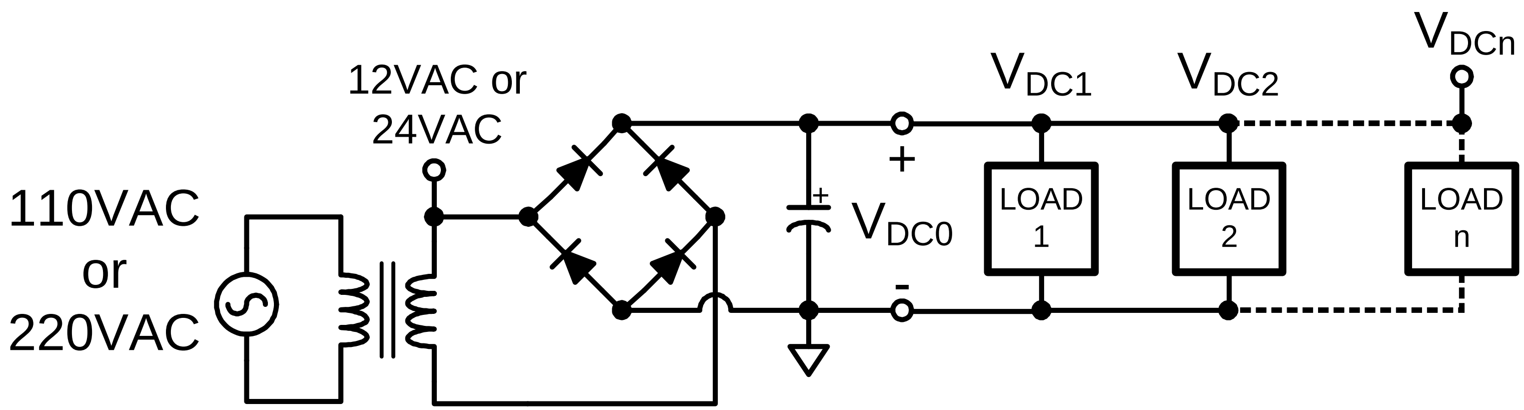
Input Voltage Can be Almost Anything

- **DC Rails have a tolerance**
  - **Ex. 24V ±2%, 5%, 10%....**

- **Rectified AC has a tolerance**



$$V_{DC0} > V_{DC1} > V_{DC2} > V_{DCn}$$

LED Driver Design Outline

1. Determine I_F and V_F range for each LED
2. Fix the arrangement of all LEDs
3. Identify total output current, voltage, power
4. Determine regulator type based on P_{OUT} and relative V_{IN} and V_O
5. Design power supply taking into account LEDs as a load
6. Use a dedicated LED driver IC whenever possible

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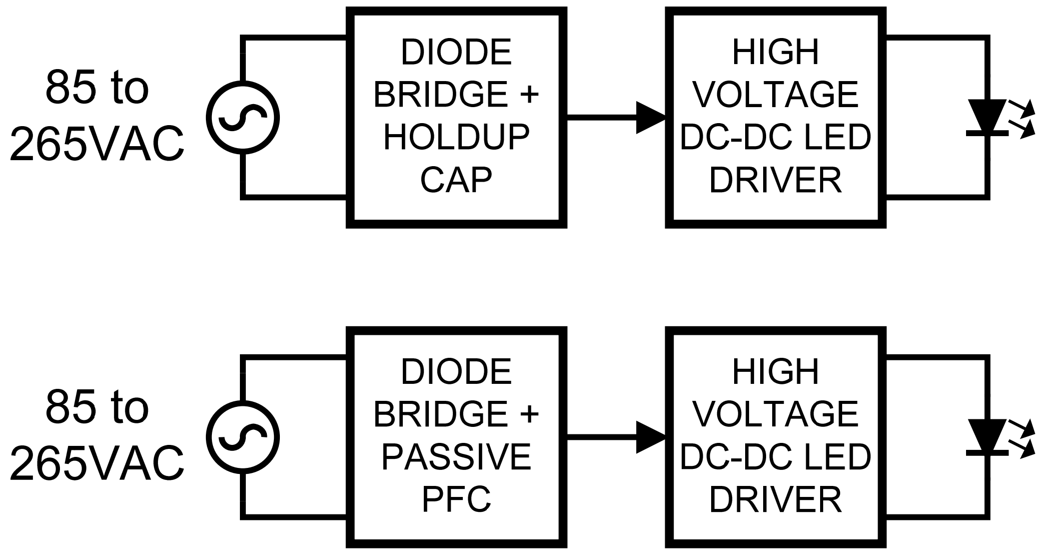
LED Driving from AC Mains

AC to CC



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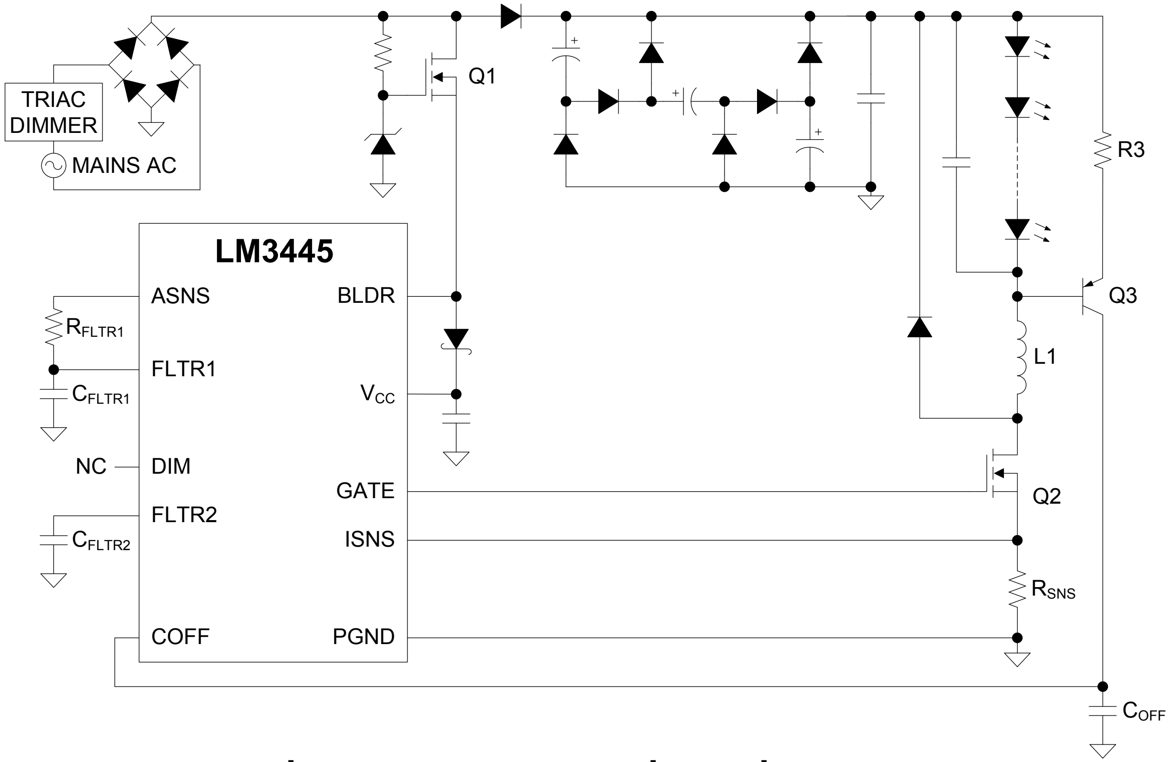
LM3445: Constant Off-Time Controller with Triac DIM Decoder for AC Inputs up to 277VAC

- V_{IN} range: 7V-14V
- Q1: High voltage FET
- Integrated 300Ω bleeder resistor for proper TRIAC operation
- Simplified Constant Off Time control scheme keeps ripple current constant
- Angle detector/decoder translates TRIAC chopped waveform to analog or digital DIM signal
- Over-current protection with 10 μs fixed off-time
- DIM is I/O which allows master-slave control in multi-chip solutions.

Target Applications:
Triac dimmer retro-fit

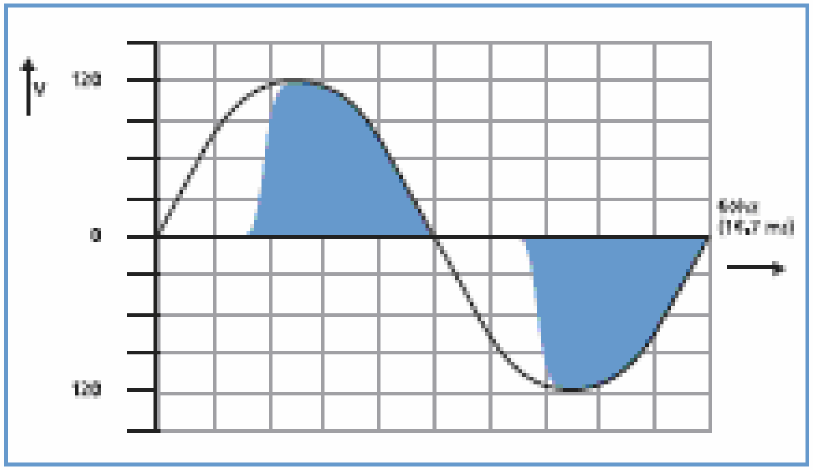
Passive PFC



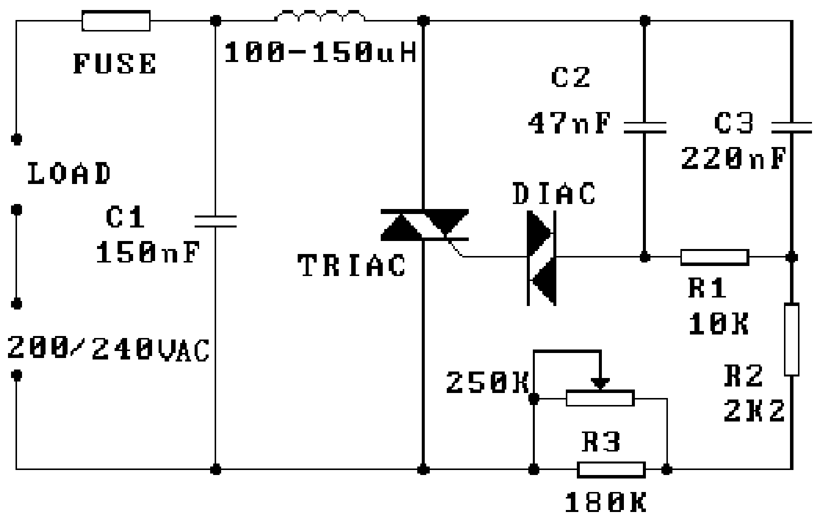
Triac or PWM Dimming

Triac 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

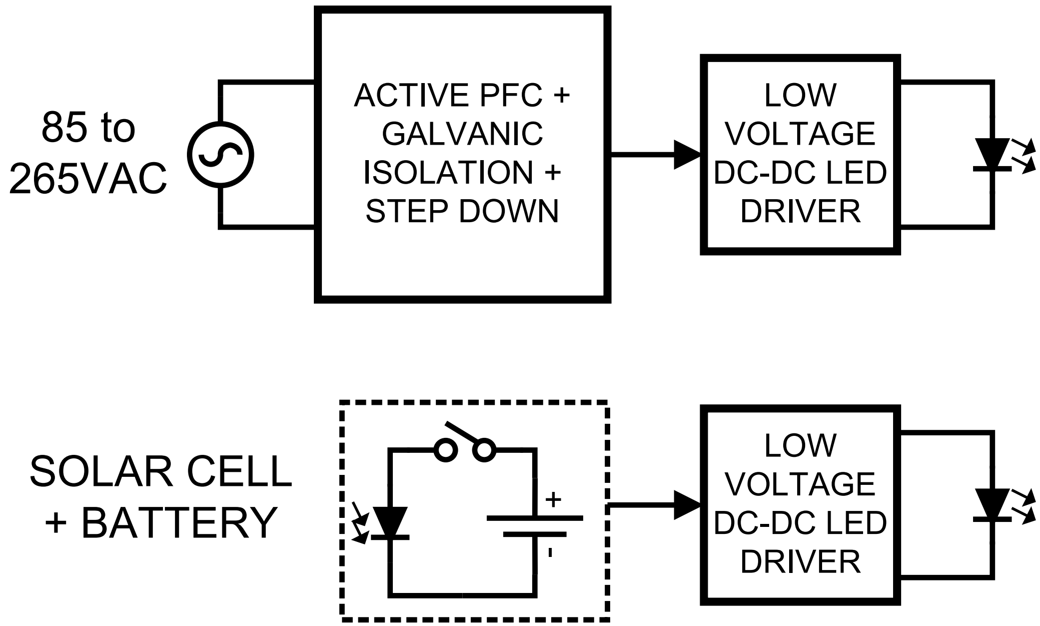


Forward phased Triac-dimmed waveform



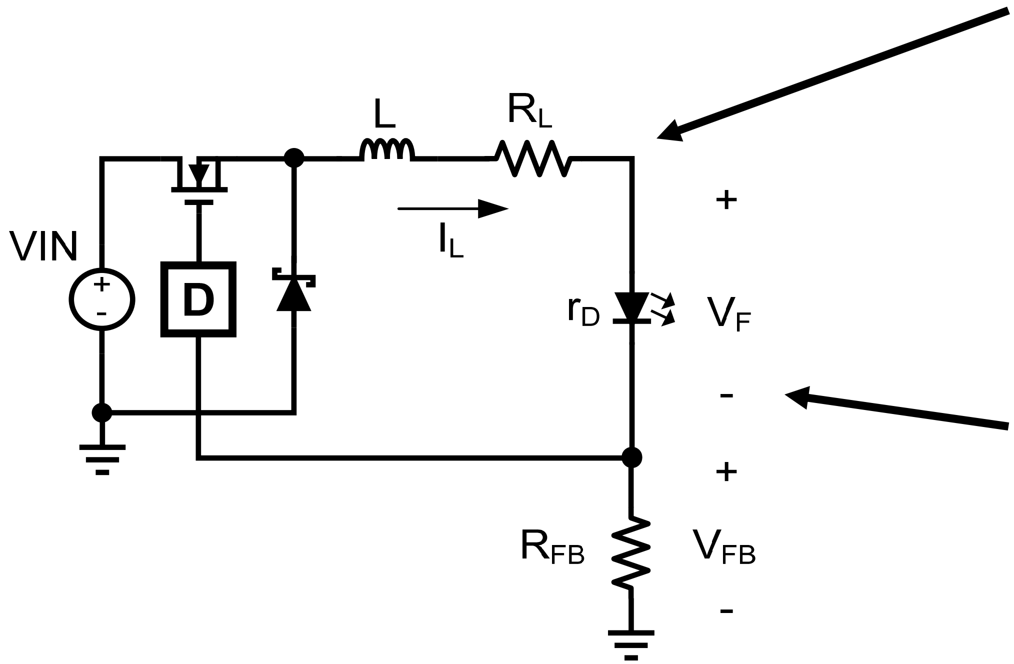
LED Driving from DC Inputs

DC to CC



Select Topology of LED Driver: Buck

- **Buck is best – use whenever possible**



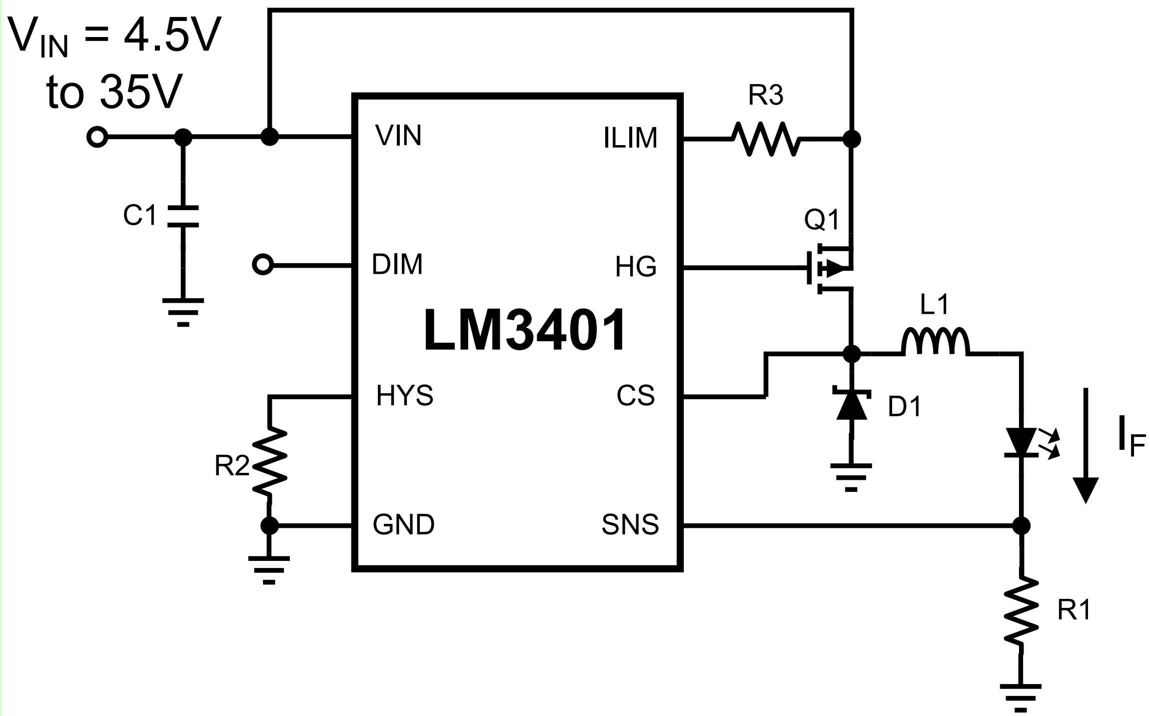
High output impedance: like a true current source

Output capacitor is optional

- **I_F slew rate is limited only by L, V_{IN}, V_F**

LM3401: PFET Controller, Buck Current Source for High Power LEDs

- **External Power FET**
  - Controls output currents up to 4A
- **100% Duty Cycle Capable**
  - Best for circuits that run close to dropout
- **Tiny MSOP-8 Package**
  - Similar size, comparable thermal performance to PSOP-8
- **Adjustable Safety Current Limit**
- **Hysteretic Control with Adjustable Window**
  - User sets LED ripple current



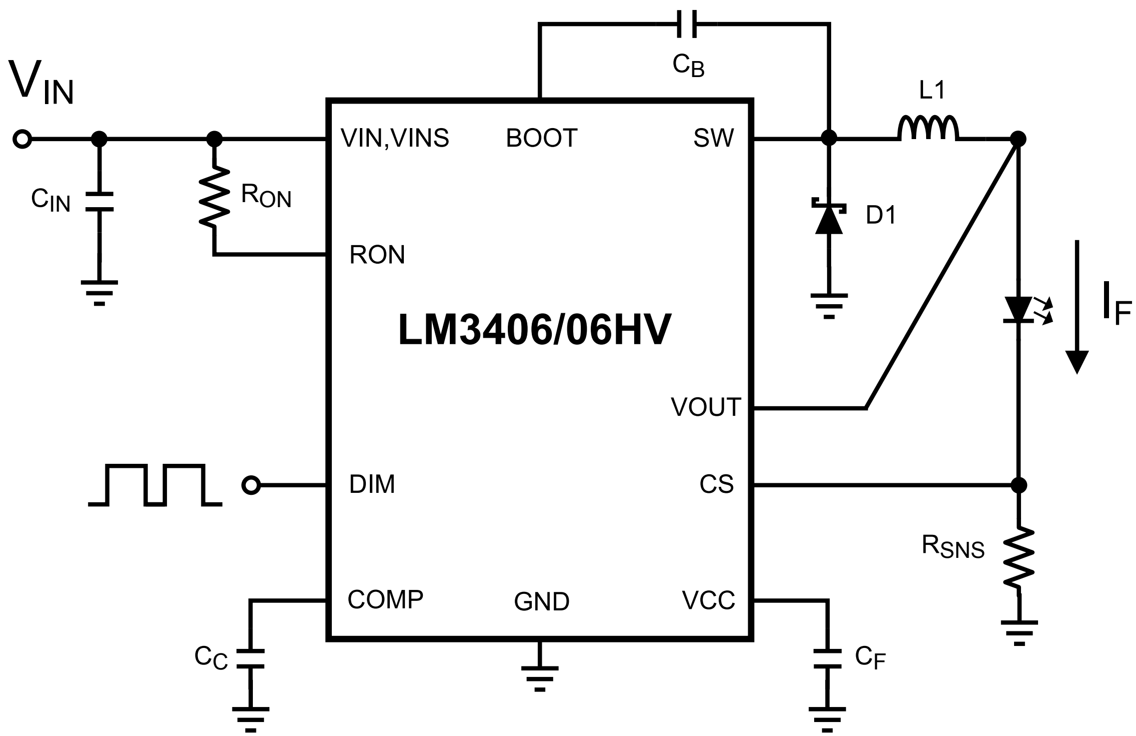
LM3406/06HV: 1.5A Buck Current Source Driver for High Power LEDs

Has All Features of LM3402 and LM3404 Plus:

- **Dedicated Error Amplifier**
  - Provides True Average LED Current Control
- **Senses V_O and Adjusts on-time**
  - Keeps f_{SW} constant over V_{IN} AND V_O
- **eTSSOP-14 Package**
  - Similar size, comparable thermal performance to PSOP-8
- **Adds Input Comparator for "Two-Wire Dimming"**
  - Eliminates one wire from harness

V_{IN} still 6V to 42V (LM3406)

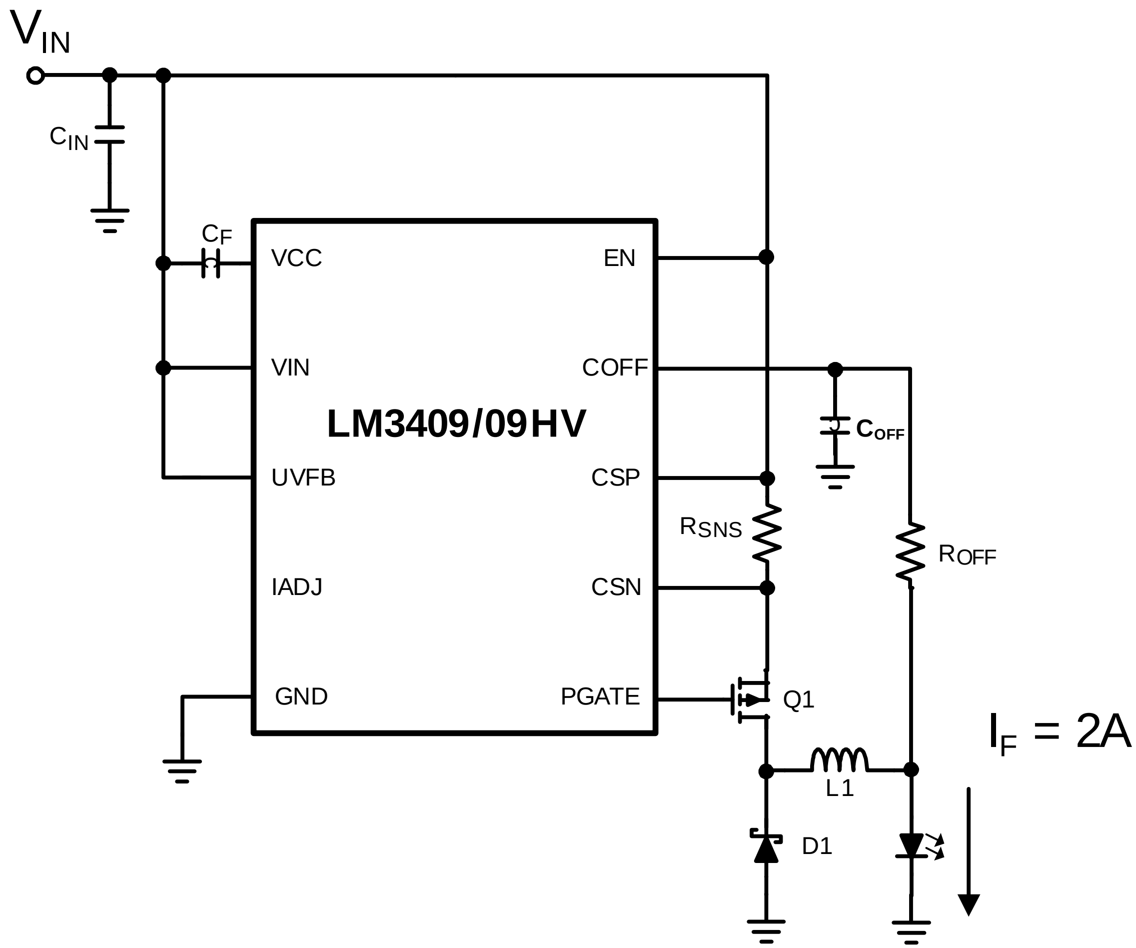
V_{IN} still 6V to 75V (LM3406HV)



LM3409/09HV: High-Side PFET Buck Controller for LEDs

Key Features:

- V_{IN} 6V to 42V (LM3409)
- V_{IN} 6V to 75V (LM3409HV)
- External power PFET
  - 100% Duty Cycle Capable
  - Output Currents up to 4A
- Differential, high-side current sense
  - Simplifies system wiring
- PWM dimming and analog dimming at 1000:1
  - Similar size, comparable thermal performance to PSOP-8
- No control-loop compensation



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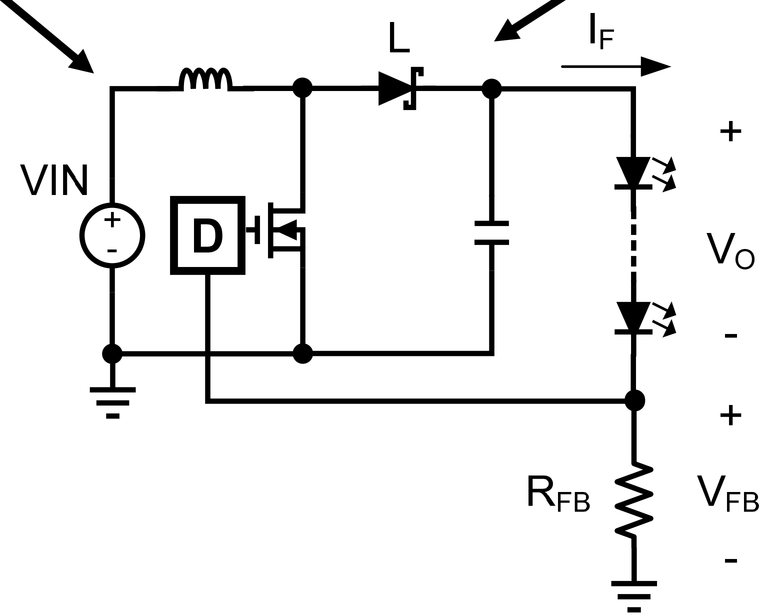
Select Topology of LED Driver: Boost

- **Necessary when Vo > Vin**

Continuous input current -> low EMC

Output capacitor is mandatory



Must have output open-circuit protection

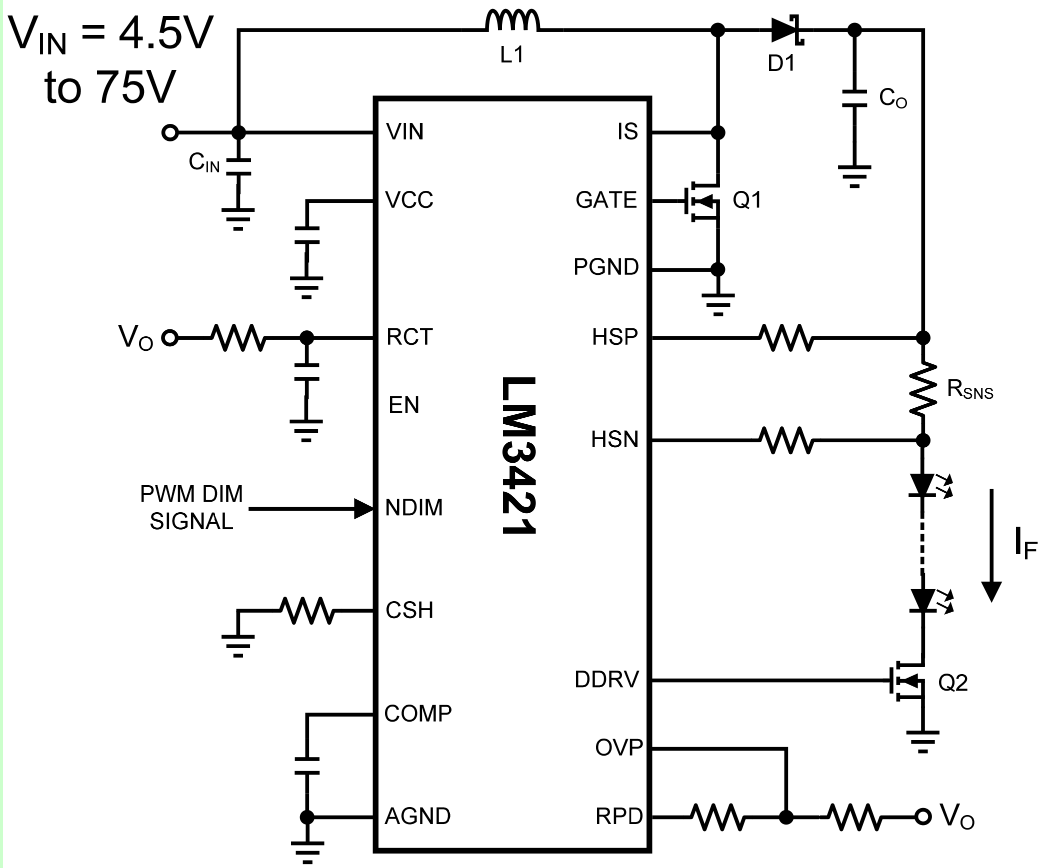
Power efficiency almost as good as buck

LM3421/23/29: Low Side Controllers for Constant Current LED Drivers

Key Features

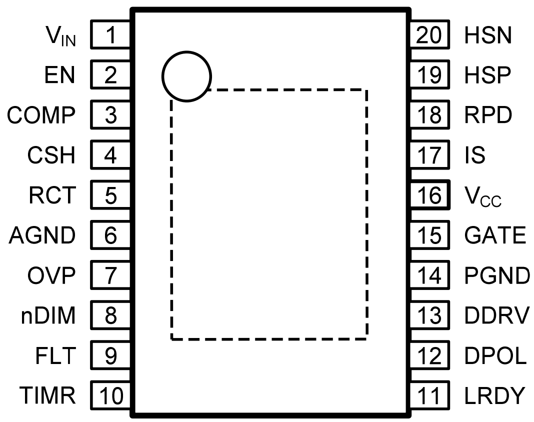
- V_{IN} Range: 4.5V to 75V
  - To Accommodate Cold Crank and Load Dump Conditions
- Fast (50 kHz) PWM dimming input, Programmable frequency
  - For greater design flexibility
- Dimming MOSFET gate driver
  - High-side dimming
- Zero current shutdown, LED ready flag, fault timer pin, Input UVLO, High side current sensing
  - For greater system reliability
- Drives 1W, 3W, and higher powered LEDs

Boost, Buck, Buck-Boost, SEPIC Topologies

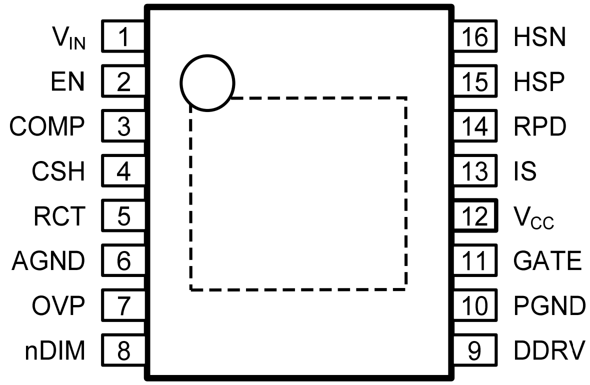


LM342x Family Options

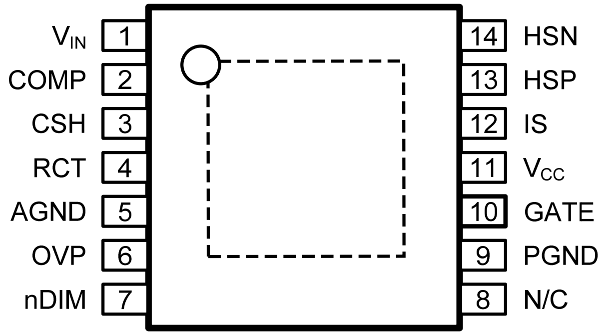
LM3423



LM3421

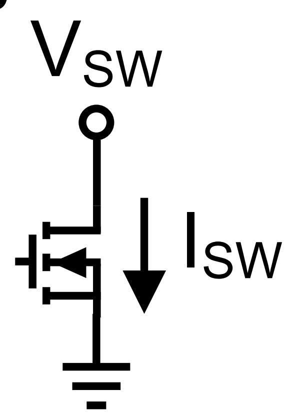


LM3429



Buck-boost: Last Resort

- May invert the polarity of V_O (single inductor buck-boost, Cuk)
- May regulate V_O with respect to V_{IN}
- May require two inductors (SEPIC, Cuk)
- May require a transformer (Flyback)
- May require up to four switches
- Are always less efficient than buck or boost
- High voltage and current stress in power switch



$$V_{SW} = V_{IN} + V_O$$

$$I_{SW} = I_{IN} + I_O$$

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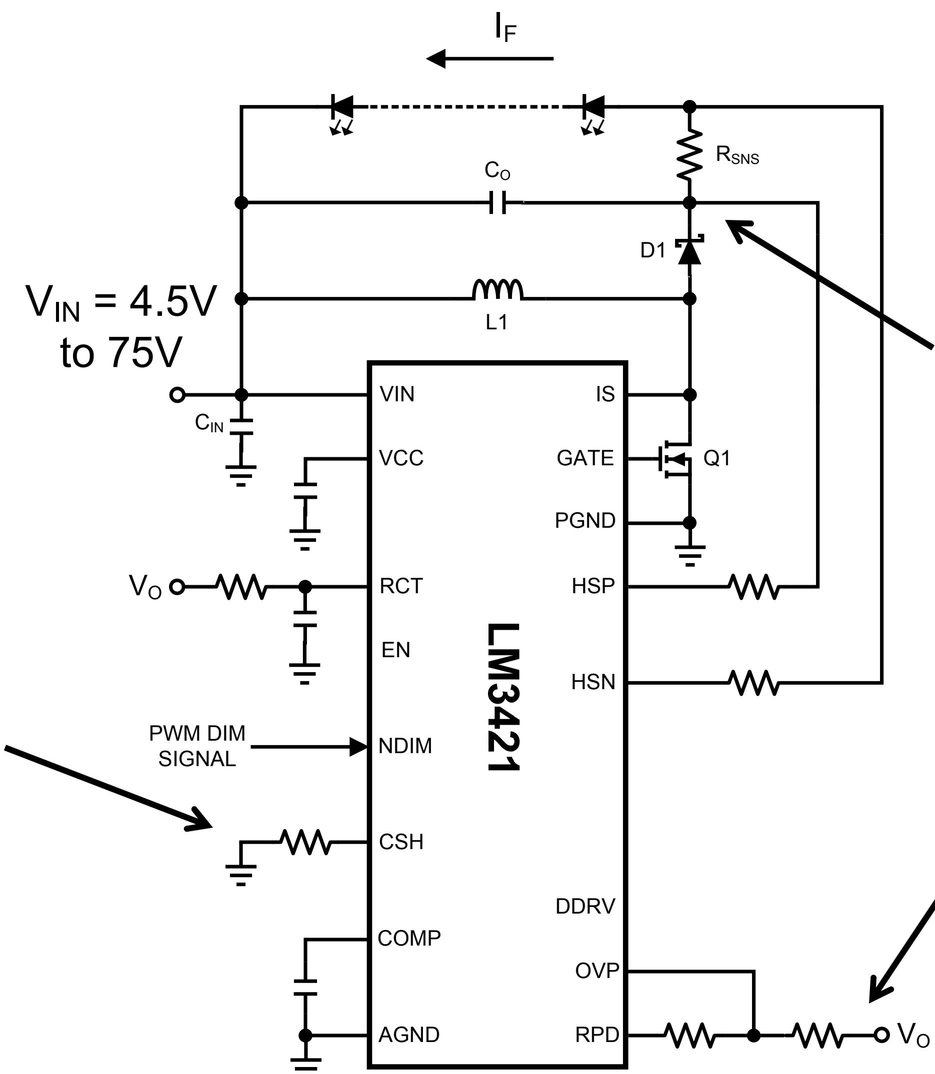
LM3421/23 Controls the "Vin-referenced" Buck-Boost



V_O controlled with respect to V_{IN}

Adjustable, precision threshold protection for LEDs that fail open-circuit

Linear I_F control

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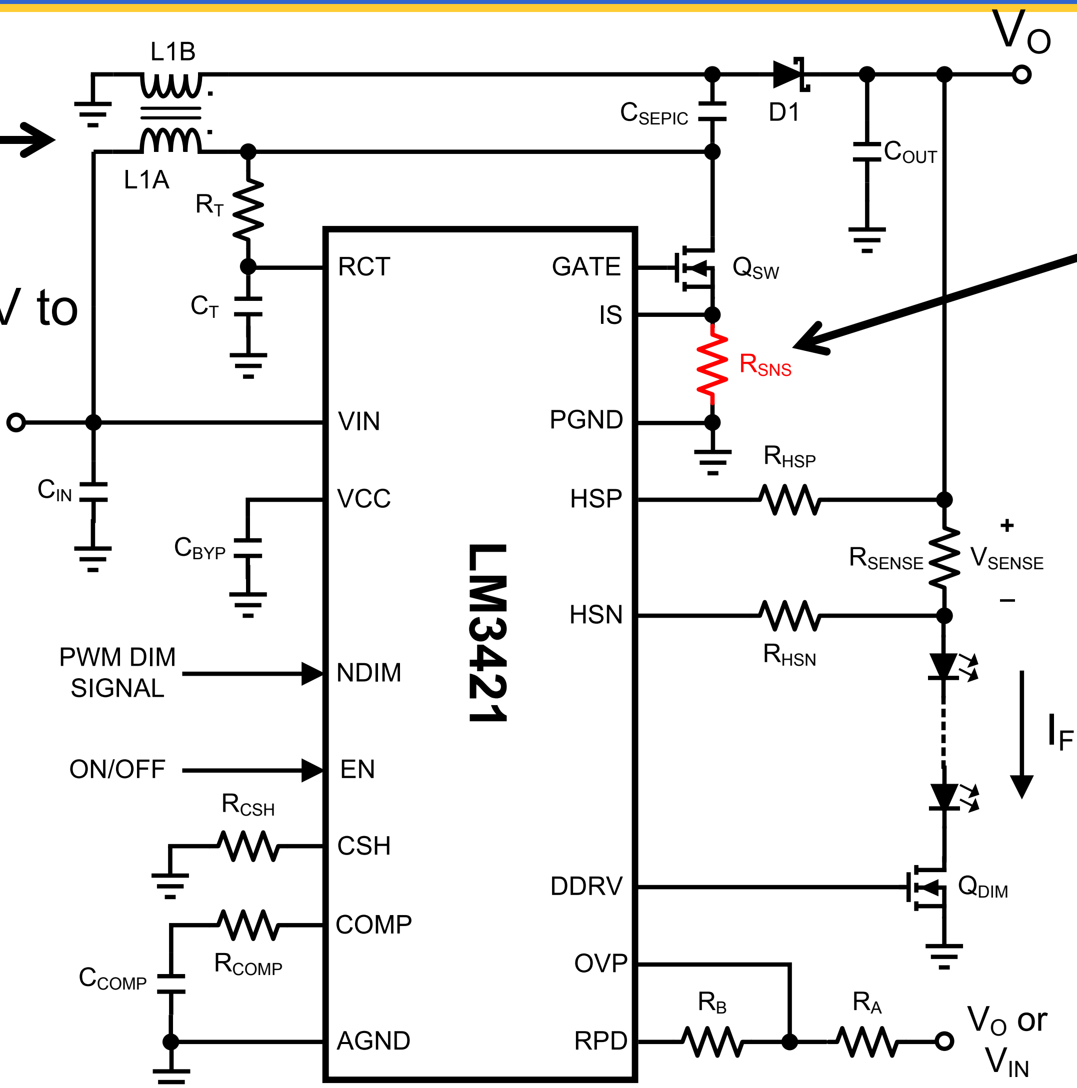
LM3421/23 SEPIC with Fast Dimming

Continuous input current

V_{IN} = 4.5V to (75V)



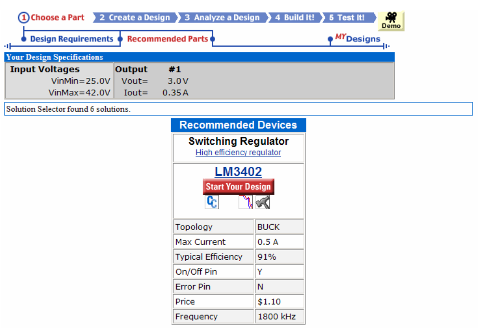
Must use discrete R_{SNS} when (V_{IN}+V_O ≥ 75V)

National's Online Tools Allows Easy Design and Analysis

LED WEBENCH ® Online

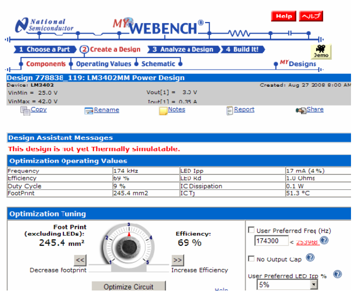
1. Choose a Part

Enter Specifications



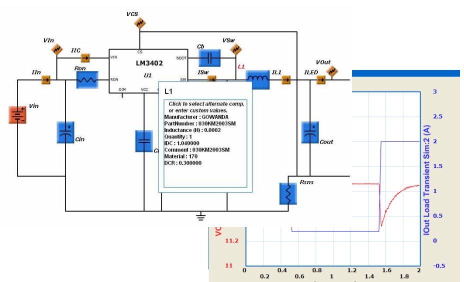
Select Part

2. Create a Design



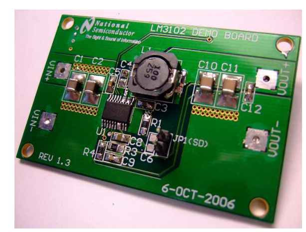
Optimize for Footprint and Efficiency

3. Analyze a Design



Generate Schematic/ Electrical Analysis

4. Build It!



Order Evaluation Board

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Reference Design Selection Tool

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46 ready designs

NSC Part Used	View Reference Design in WEBENCH®	Get Report	Description	PADC ID	Vin min (V)	Vin max (V)	Vout max (V)	Iout (A)	Pout (W)	Efficiency (%)	Switch Freq (kHz)
LM2623	Open Design	PDF	LM2623 Boost regulator LED driver;	PADC_NSC0119	1.5	3.3	3.5	0.35	1.22	84.0	2000
LM2623A	Open Design	PDF	High efficiency, step-up regulator LED driver for battery-powered and low input voltage systems;	PADC_NSC0498	1.8	3.4	3.5	0.65	2.28		2000
LM2698	Open Design	PDF	LM2698 8x4 LED array driver with PWM dimming;	PADC_LED005	5.0	5.0	16.0	0.16	2.56		1250
LM2700	Open Design		LM2700 Boost converter LED Driver; constant current source;	PADC_NSC0247	2.7	3.6	3.0	1.0	3.0		1250
LM2700	Open Design		LM2700 Boost Luxeon V LED driver with PWM dimming;	PADC_NSC0336	2.4	4.5	5.4	0.7	3.78		1250
LM2737	Open Design	PDF	Solar cell input LED driver that drives one high power LED at 2A; PWM dimming;	PADC_LED002	12.0	14.0	3.0	2.0	6.0		2000

URL: http://www.national.com/webench/ledrefdesigns.do

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  - **Products selected by strict power-to-performance efficiency metrics in 25 product categories**
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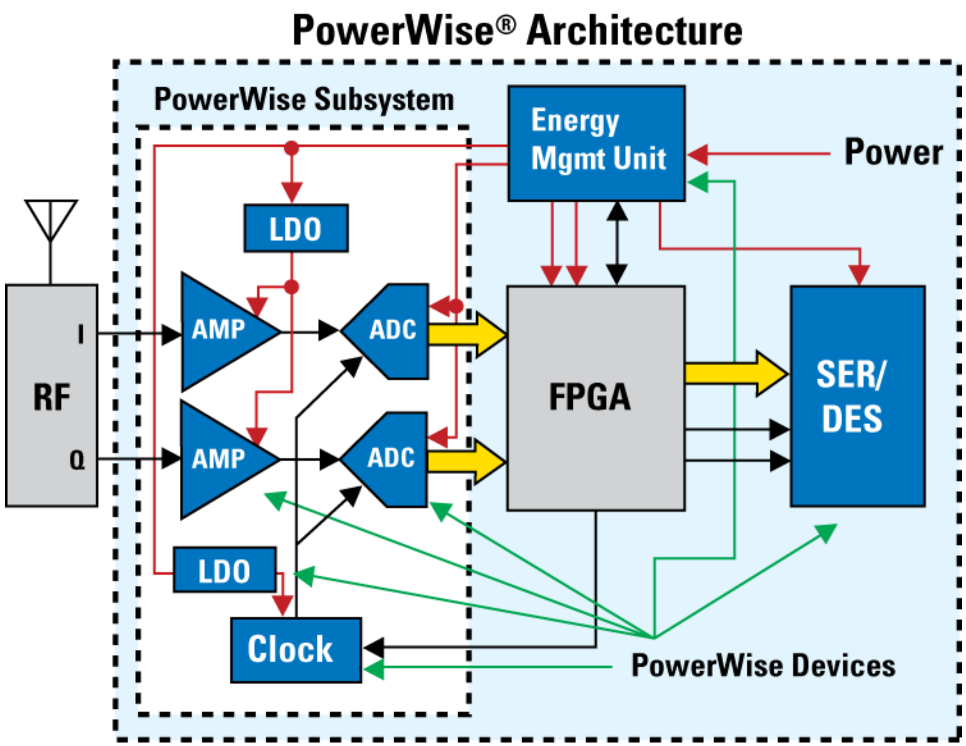

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