LED Applications and Driving Techniques

Chris Richardson

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- LED Basics
- LED Applications
- LED Driving Techniques
- LED Dimming and Contrast Ratios
- Lighting Resources and Tools

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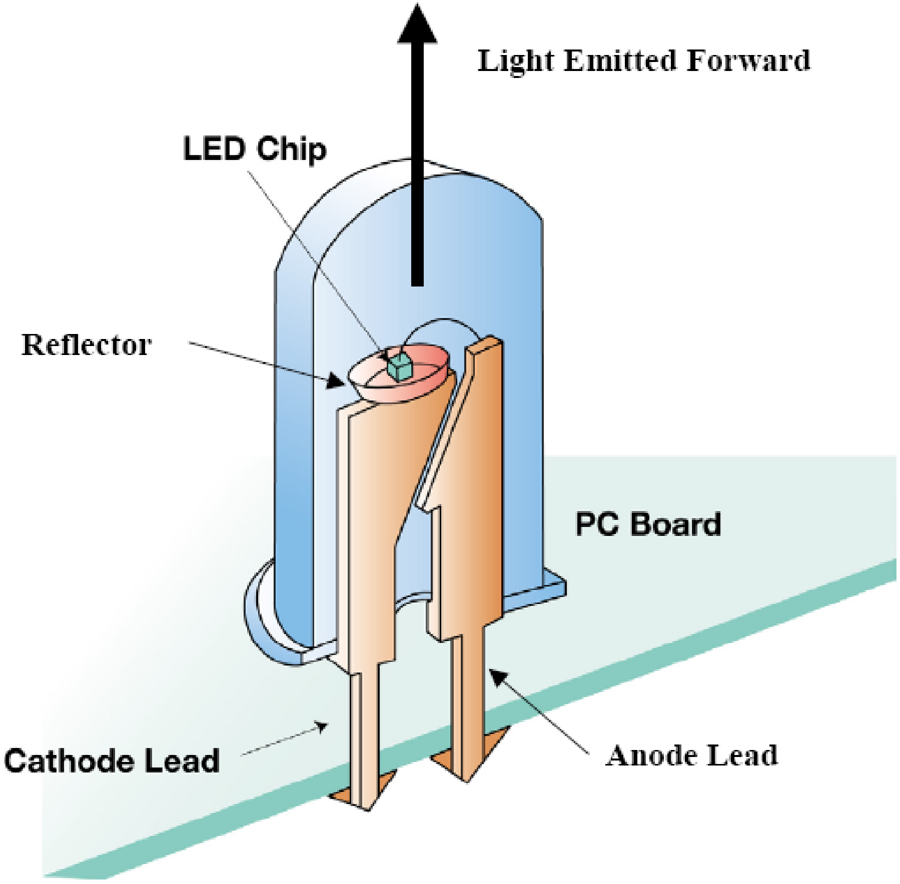
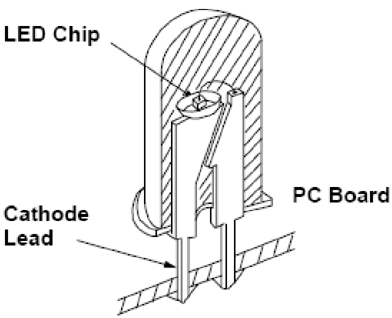
LED Basics

What is an LED?

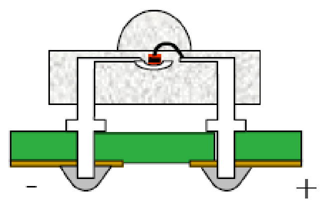


LED Development



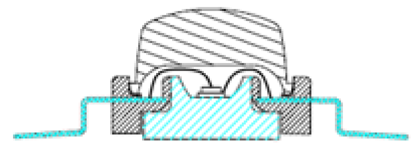
5mm Lamp
2-3 lumens
I_F = 30mA

1970



SuperFlux
4-8 lumens
I_F = 70mA

1992



Luxeon
20-40 lumens
I_F = 350mA

1997

Lumileds
Osram
Cree
Seoul Semi
Avago

I_F = 700 to 1.5A

2007

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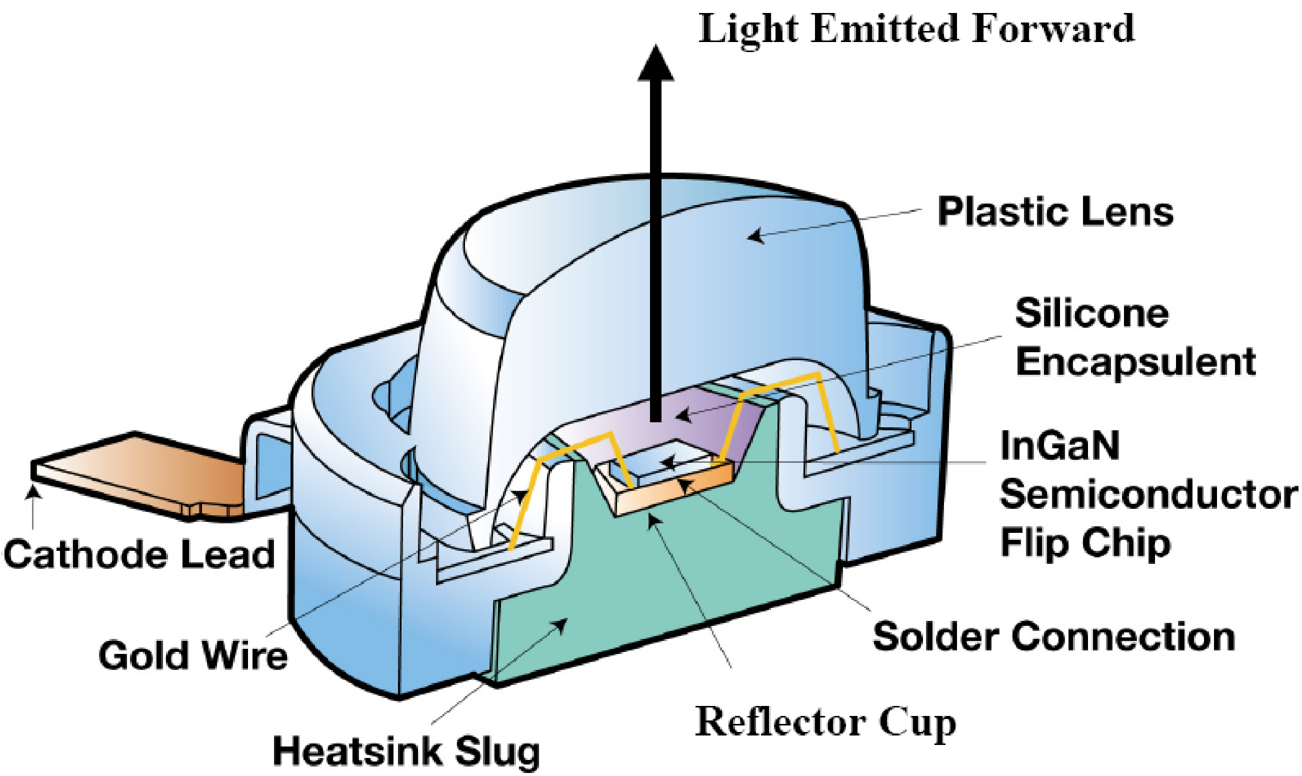
Structure of High Brightness LED



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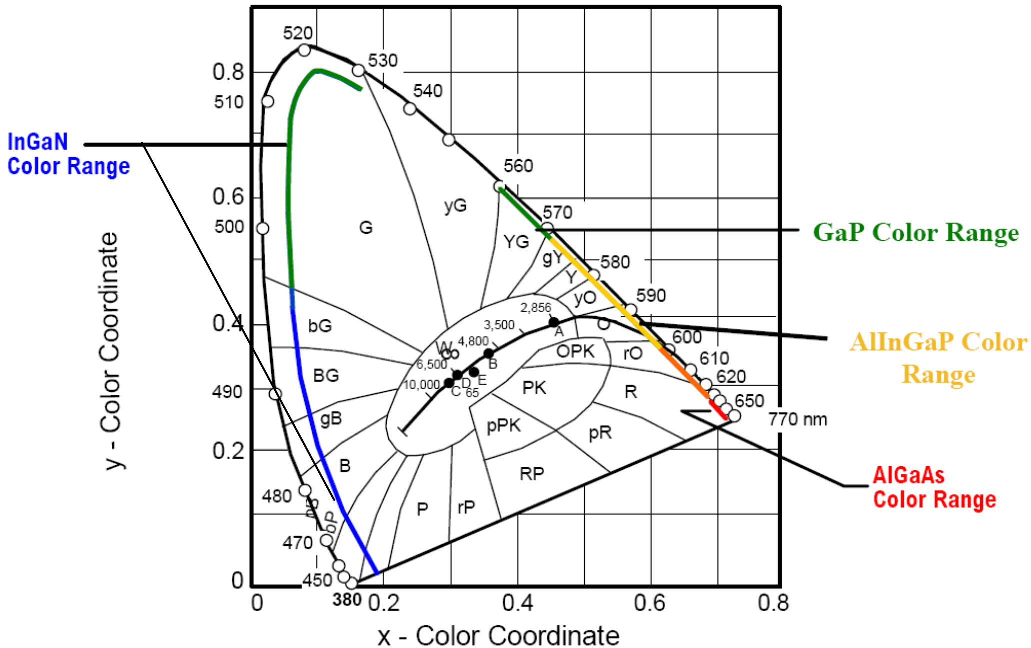
Materials used in color LEDs



White LED:

White light is generated by blue LED striking a phosphor coating

Many New Applications Have Emerged Because......

- **Typical spec. of HB LED**
  - 1 Watt LED
    - Full intensity 350mA, Maximum current 500mA
    - 2.8V Volt drop @ 350mA
  - 3 Watt LED
    - Full intensity 700mA, Maximum current 1A
    - 4.3V Volt drop @ 700mA
  - 5 Watt LED (multi-die package)
    - Full intensity 700mA, Maximum current 1A
    - 7.1V Volt drop @ 700mA
  - 5 Watt LED (single-die)
    - Full intensity 1.5A

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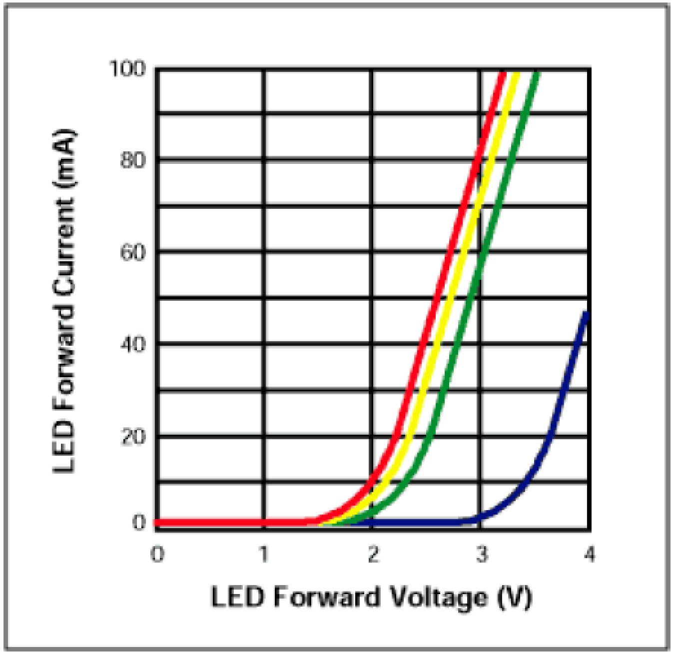
Characteristics of LEDs

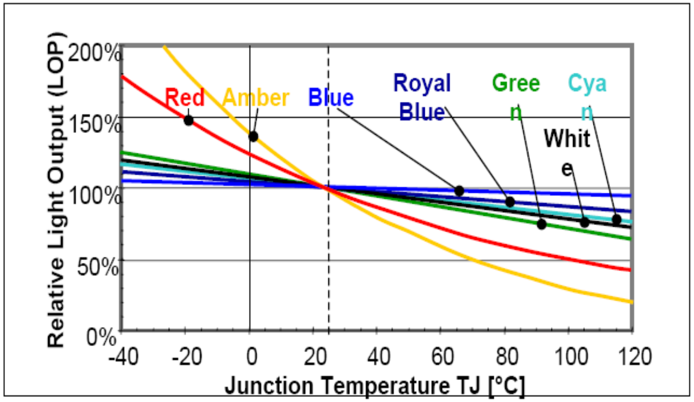
- Forward Voltage (V_F) drop across LED
  - Diodes are current driven!
- Wavelength variations
  - Crystal and junction growth defects
- Brightness variations
  - Crystal defects resulting formation of phonons and non-radiation energy transfer
- Temperature
  - Junction temperature of the device affects each of the parameters above

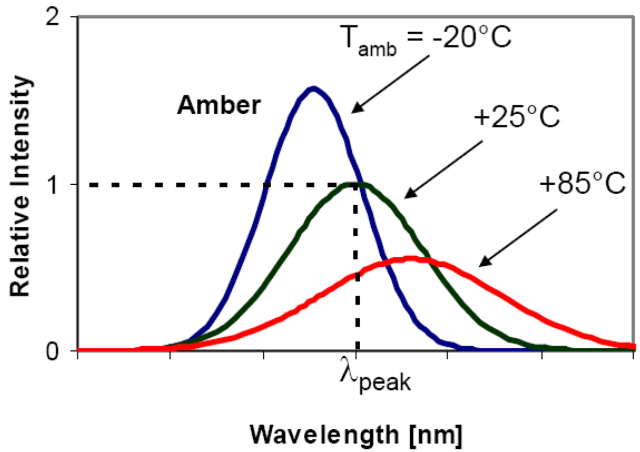


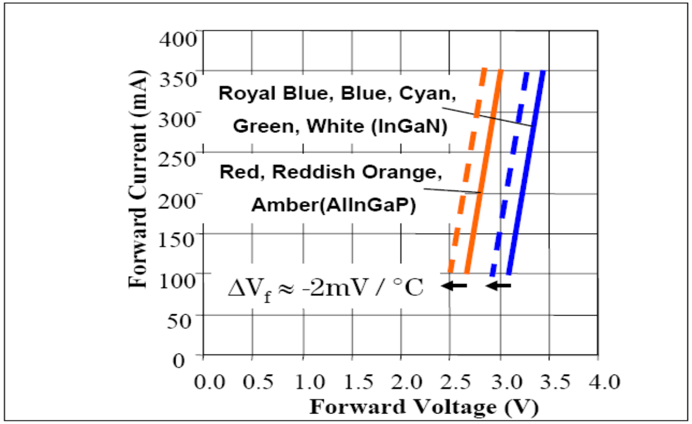
Temperature effect on LED Parameters

As Temperature increases:

- Light output decreases
- Wavelength gets longer
- Forward voltage decreases

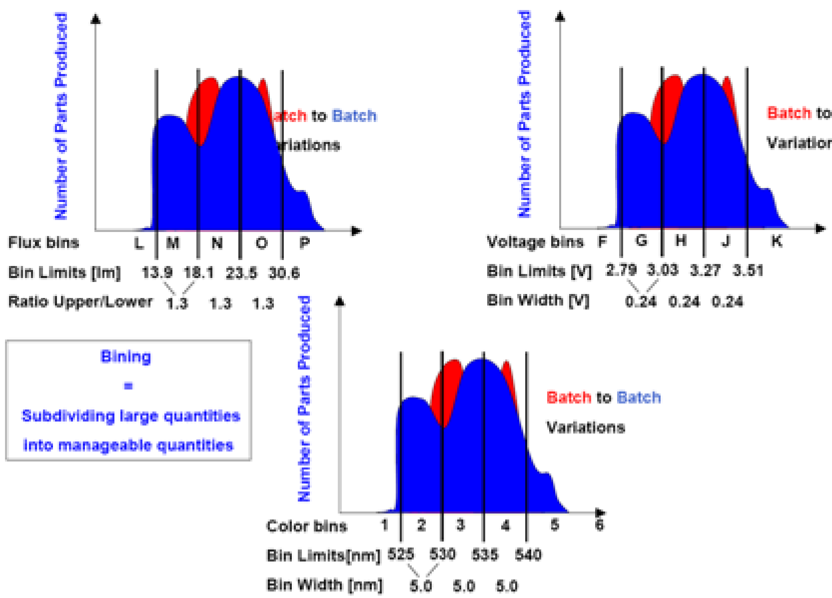






LED Binning

- **Manufacturers bin their devices for color/wavelength, brightness, and forward voltage**
- **Binning for all three characteristics is expensive, and forward voltage is often the specification that is allowed to vary the most**



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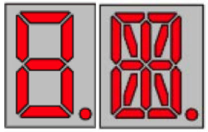
LED Applications

LED Applications

- Old days
  - Signal Indicators

  - Numeric and Alpha-numeric displays



- Nowadays
  - Automotive

  - Backlights
  - Flashlights for portable device

  - General illumination

  - Projector Light Sources
  - Signage
  - Torch Lights

  - Traffic Lights

Backlight Applications

- Possible because of white LED development
- Almost all mobile phone color LCDs use white LED backlighting.
- Size of displays from smallest to largest
  - 1. Mobile phones, PDAs
  - 2. Automotive, aerospace infotainment
  - 3. Laptop displays
  - 4. Desktop PC monitors
  - 5. LCD televisions

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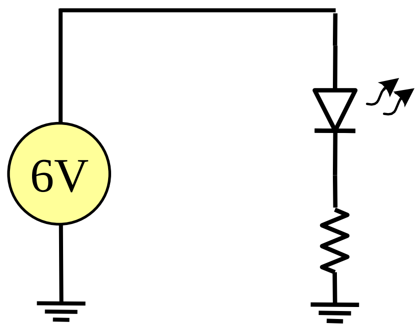
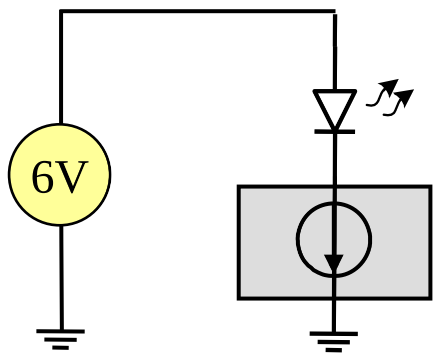
LED Driving Techniques

Resistor Limiting, Linear Regulation



Resistor Limiting



Linear IC with
Constant Current Source

Heat dissipation in resistor or linear IC

LED Driving Circuit ……

- **Delivers a constant average current under all conditions (eg. input voltage change, temperature change, V_F change……)**
- **Controls ripple current at acceptable level under all conditions**

A LED driving circuit is a type of power conversion circuit that delivers constant current instead of constant voltage

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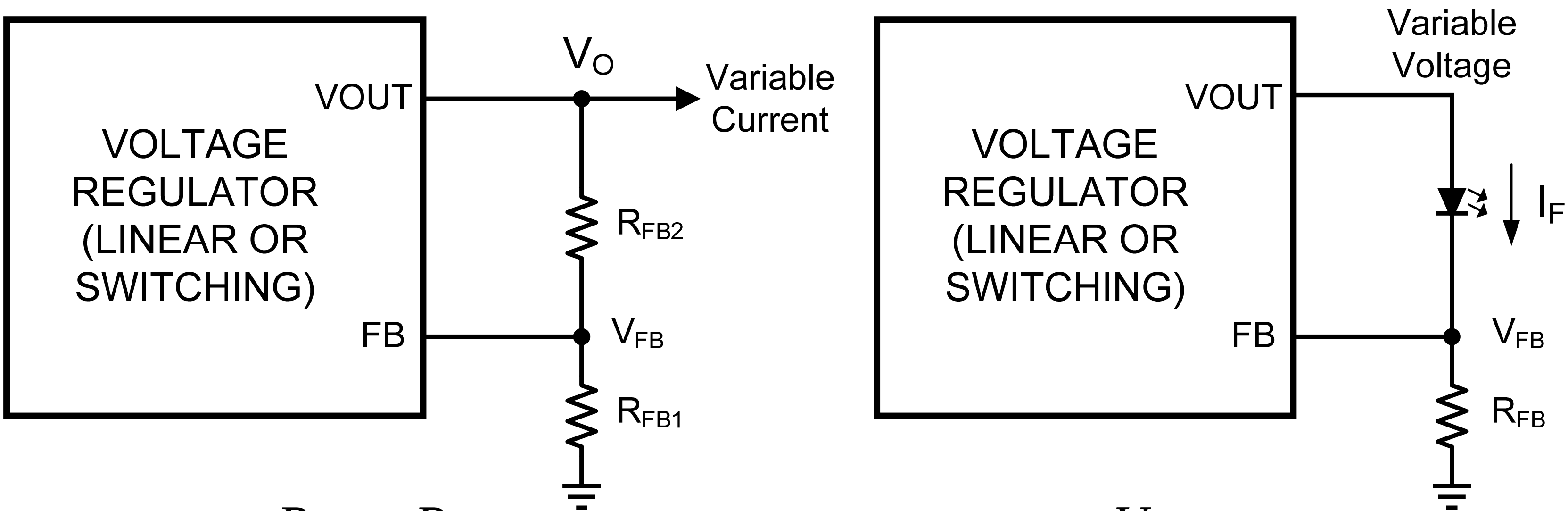
Constant Voltage to Constant Current Conversion:



$$V_O = V_{FB}\frac{R_{FB1} + R_{FB2}}{R_{FB1}}$$

$$I_F = \frac{V_{FB}}{R_{FB}}$$

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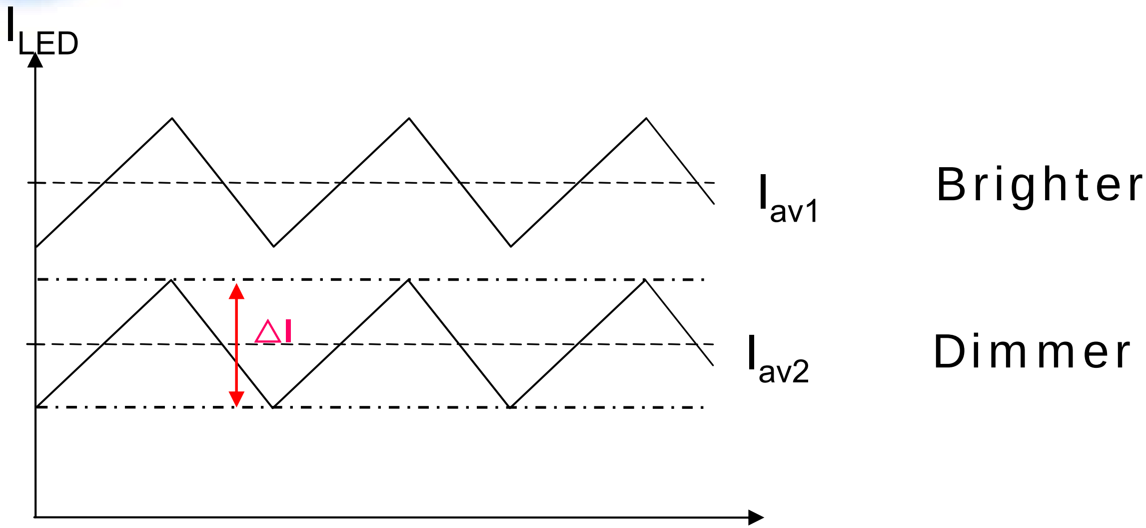
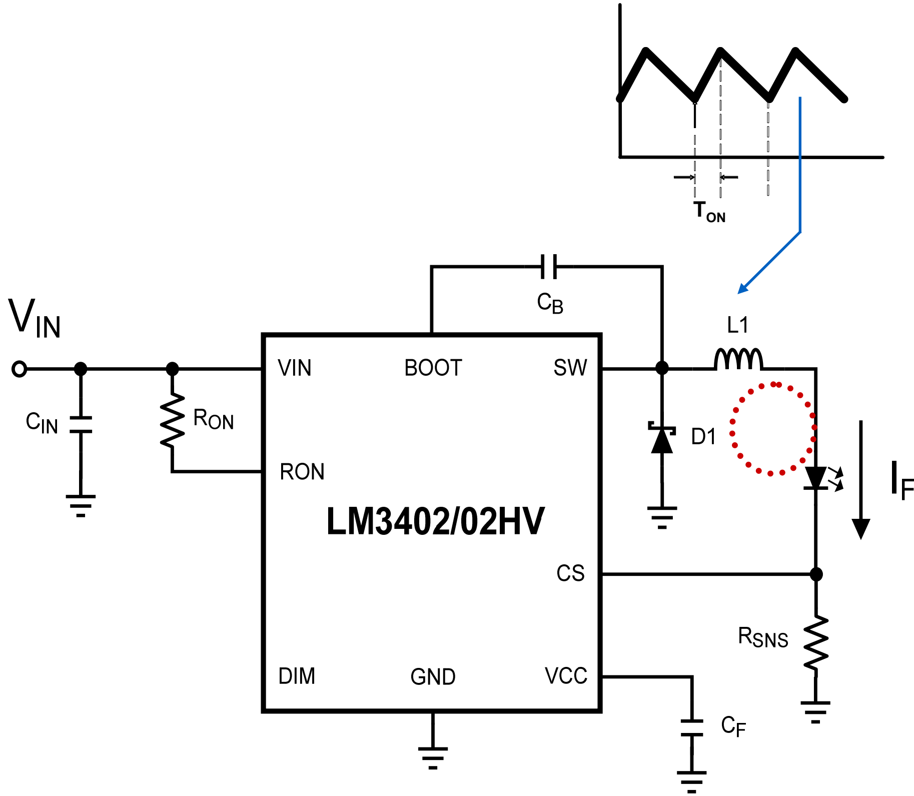
Average Current and Ripple Current



- $I_{av1} > I_{av2}$, thus I_{av1} is brighter than I_{av2} but color also changes
- Human eye cannot detect the high frequency ripple current
- Human eye cannot detect shift in average current of < 20%

Buck LED Driving

- V_O must be lower than V_{IN}
- Output capacitor is optional
- Typical Application: general lighting



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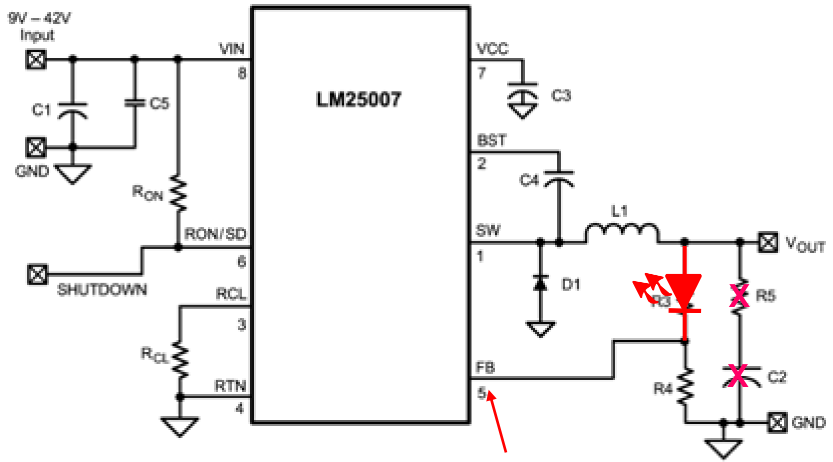
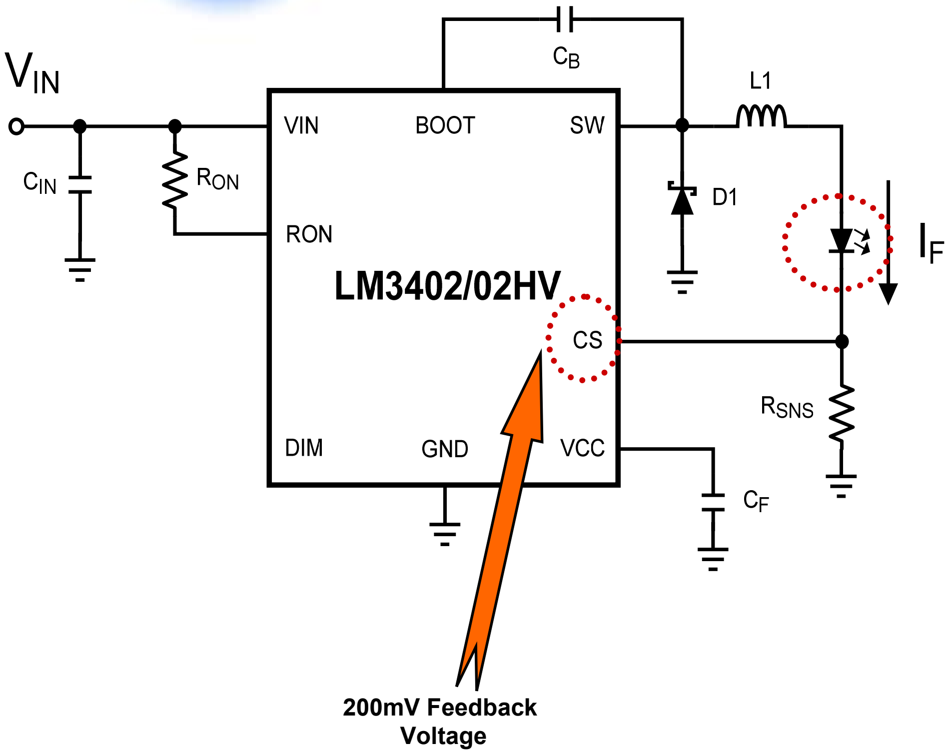
Buck Driving – How it works



- **If R4 = 5Ω, current passing through R4 = 0.5A. Current passing through the LED is also the same because FB is a high impedance pin.**
- **LED current setting can be done by R4.**

Problem: Power dissipation at R4 = 1.25W!

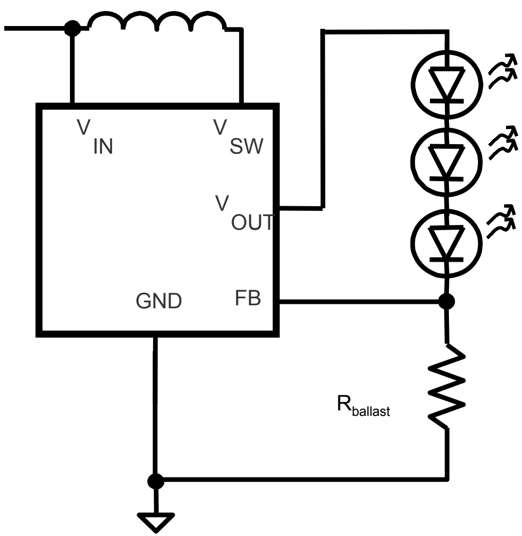
Dedicated Buck LED Driver



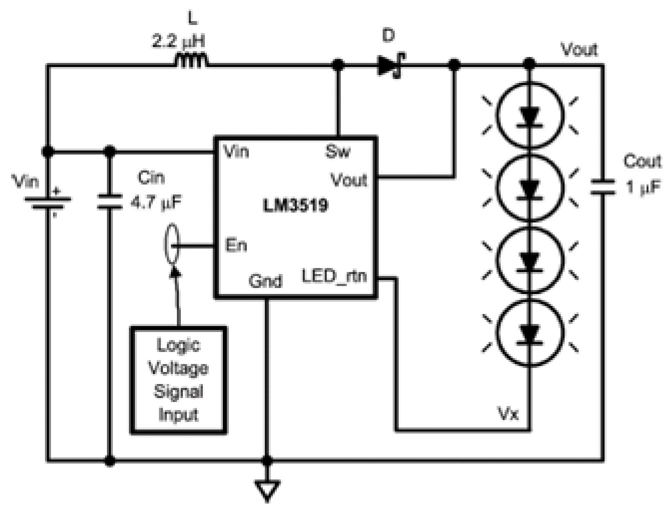
- FB voltage is reduced to 200 mV
- Power dissipation at R_{SNS} = 0.5A × 0.2V = 0.1W.

Using Boost Regulator: Series LED Connection

- **Pros:**
  - **Matching Guaranteed**
  - **Most efficient drive method**
  - **Easy to route (Only 1 or 2 connections between driver and LEDs)**
- **Cons**
  - **High voltage output is needed**
  - **Output capacitor typically large due to voltage requirement**



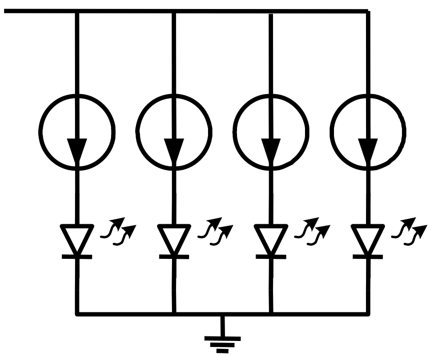
With external ballast



With internal current sink

Using Boost Regulator Parallel LED Connection

- **Pros**
  - **Workable with low-voltage semiconductor processes**
  - **Can work with common anode or common cathode module**
- **Cons**
  - **Good matching requires regulated current sources**
  - **Requires 1 connection per each LED i.e. driver IC requires more pins**



Constant current source connection

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Boost: Inductor based vs Charge Pump

	Charge Pump	Inductor Based
LED Connection	Usually Parallel	Usually Series
Efficiency	Depends on V_{IN}, V_O, and gain mode	Reduced dependence on V_{IN} and V_O
PCB Space	Less	More
Wide Vin – Vout Support	Not Practical	OK
EMI Generation	Less	More, due to presence of inductor

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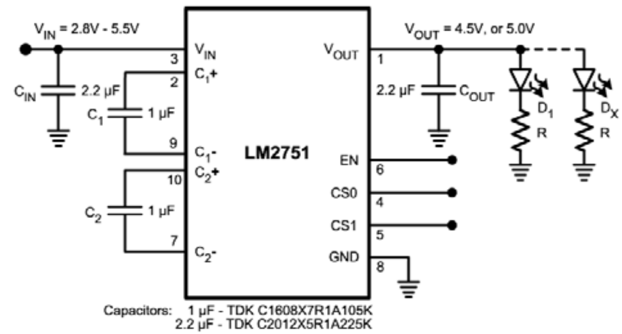
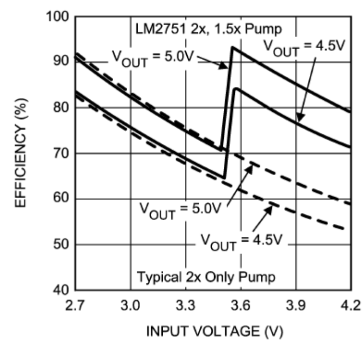
Efficiency of a Charge Pump

- **Charge pumps are very efficient if V_{IN} x Gain is close to target V_O**
- **Efficiency drops off as V_{IN} increases.**
- **1.5 x mode is introduced to boost efficiency in conversion from one Li-ion battery to 5V V_O**



LM2751 2x/1.5x Efficiency vs.
2x Charge Pump Effciency



LM2751 - 2×, 1.5× charge pump (switched capacitor) white LED driver which can deliver up to 150mA at 725KHz switching frequency.

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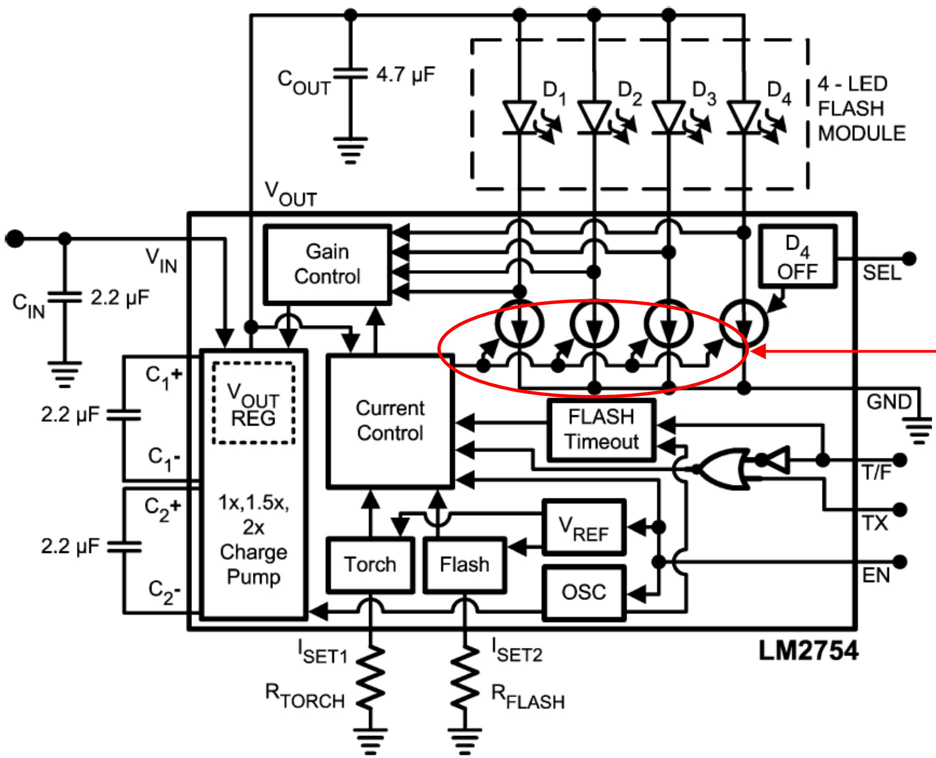
Charge Pumps with built-in Current Source



Built-in current source, better current matching in driving several LEDs.

LM2754 - 2×, 1.5× charge pump (switched capacitor) white LED driver which can deliver up to 800mA at 1MHz switching frequency.

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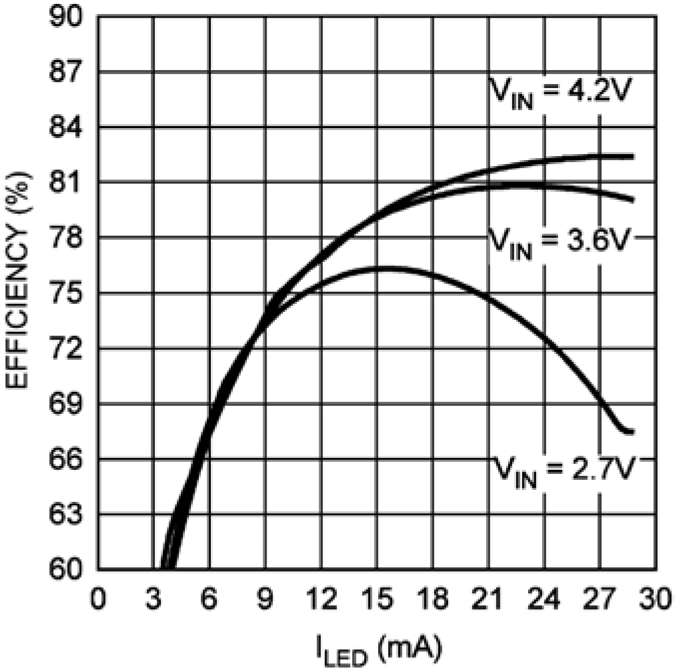
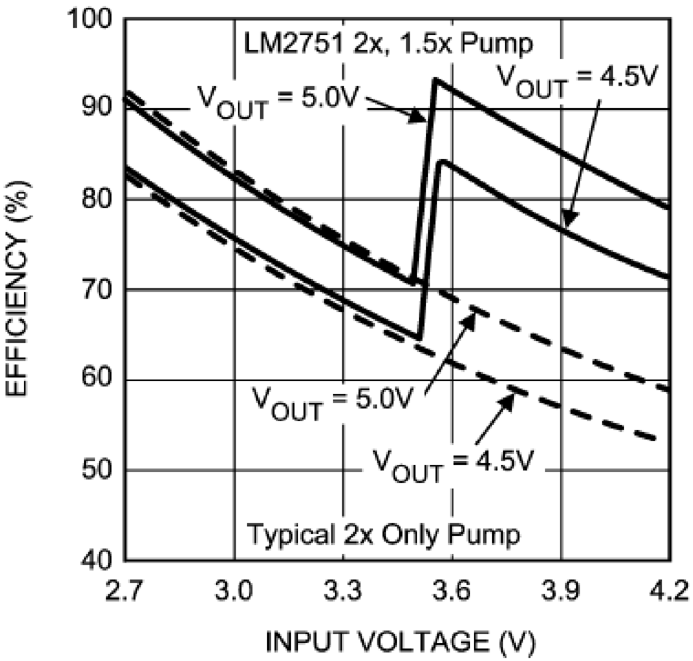
Inductive vs Charge Pump Efficiency Comparison

LM3508 Inductive Boost Efficiency



LM2751 2x/1.5x Efficiency vs. 2x Charge Pump Effciency



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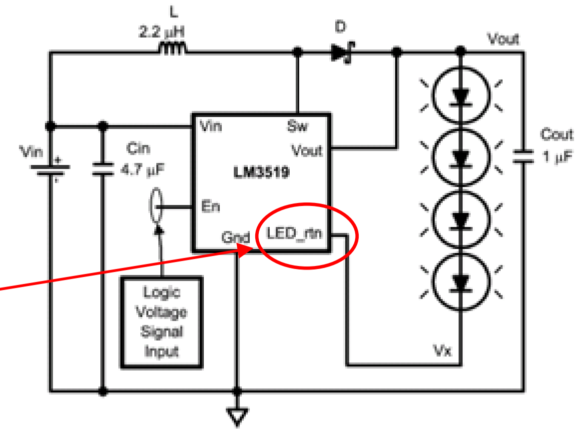
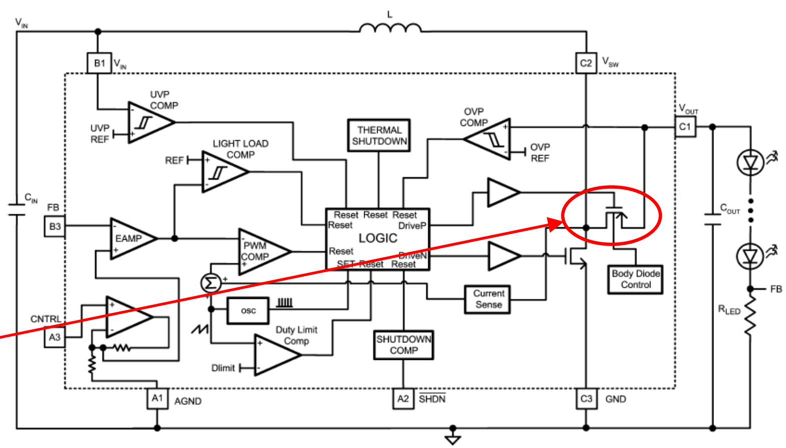
True Shutdown Isolation

- **Method 1**
  - Add switch in return path.



A switch is added to cut off leakage path during shutdown

- **Method 2**
  - Synchronous rectification.

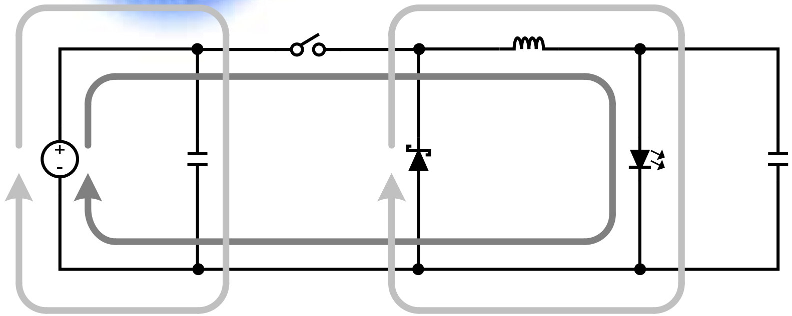


Diode is replaced by MOSFET and it is switched off during shutdown

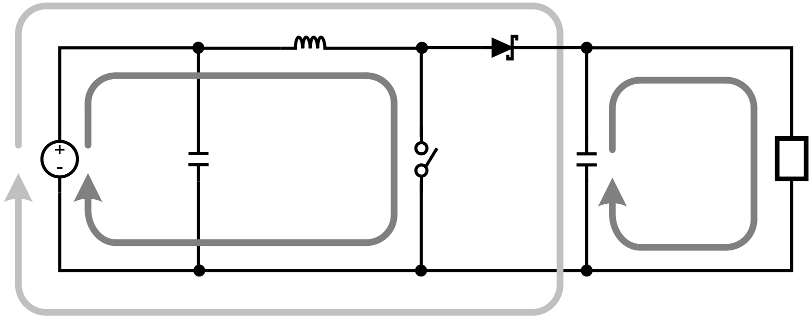
Bucking and Boosting

- High power LEDs are being adopted into portable lamps (bicycle, mining, flashlight) with varying number and chemistry of batteries
- Low-voltage AC lighting (garden path) varies due to I^2R loss
- Combine varying V_{IN} with V_F that changes with process and temperature
- Requires true buck-boost regulator

Buck Boost Efficiency < Buck or Boost



Buck: Input direct to output when power switch is on

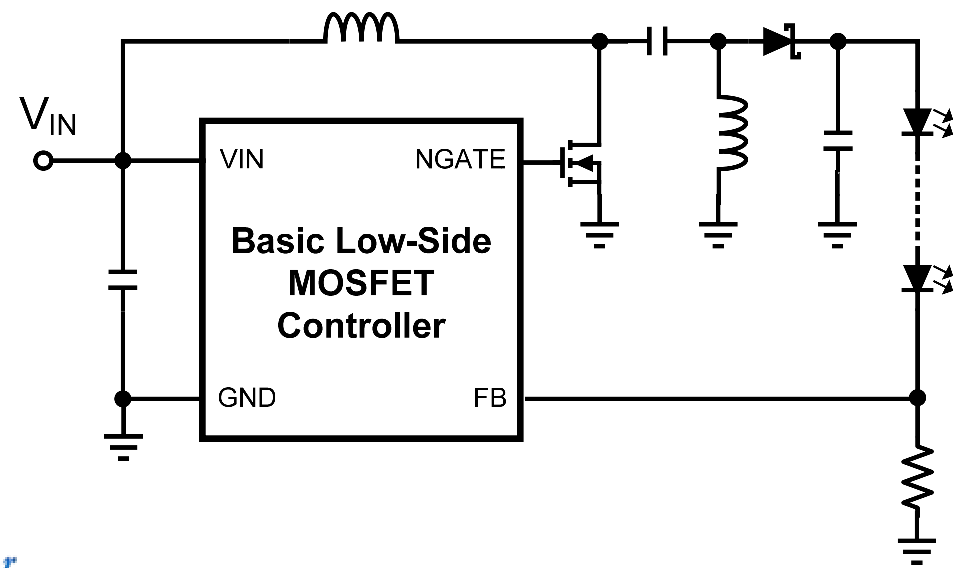


Boost: Input direct to output when power switch is off

Buck-boost: input is never connected directly to output

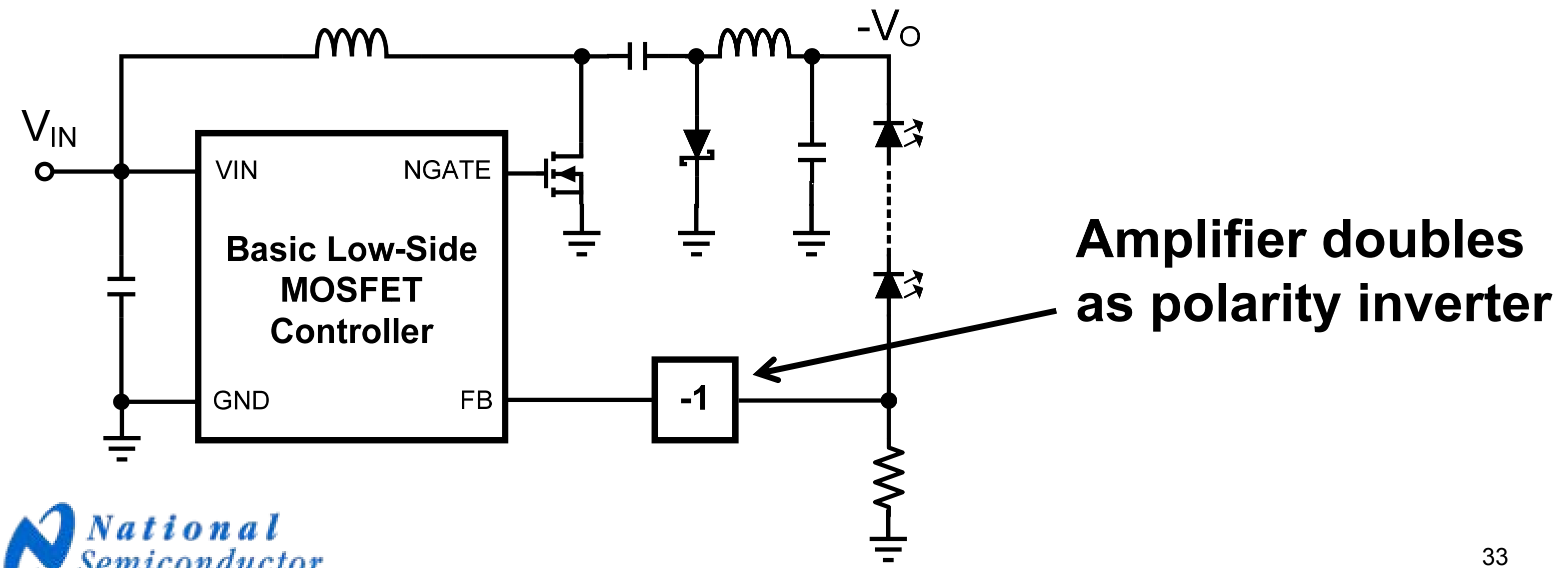
Buck-Boost Driving: SEPIC Regulator

- Uses standard low-side regulator/controller
- Low-side or high-side current sensing
- Requires two inductors or coupled inductor
- Requires an output capacitor

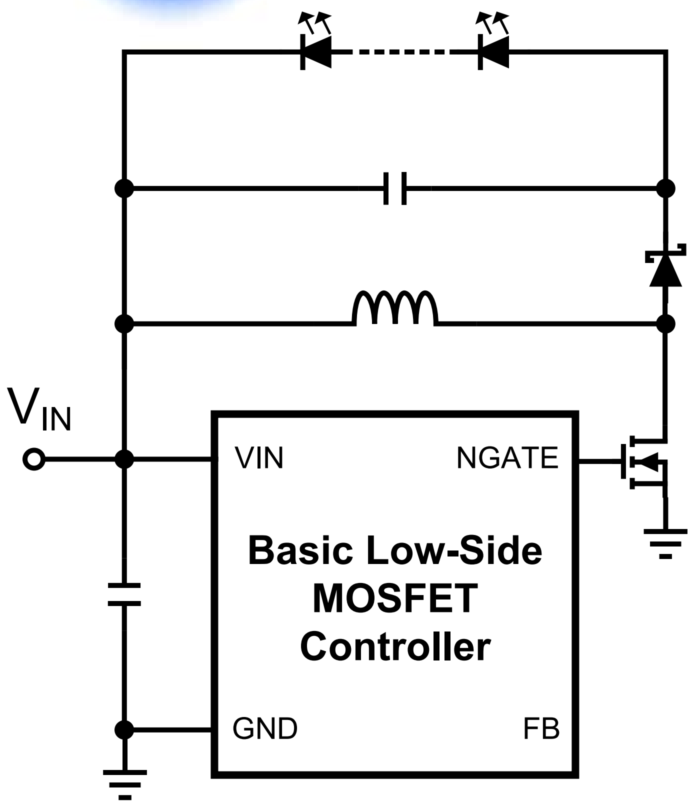


Buck-Boost Driving: Cuk Regulator

- Uses low-side regulator/controller but requires negative FB pin
- Low-side or high-side current sensing
- Negative V_O doesn't matter in current drivers
- Requires two inductors or coupled inductor
- Can run without C_O



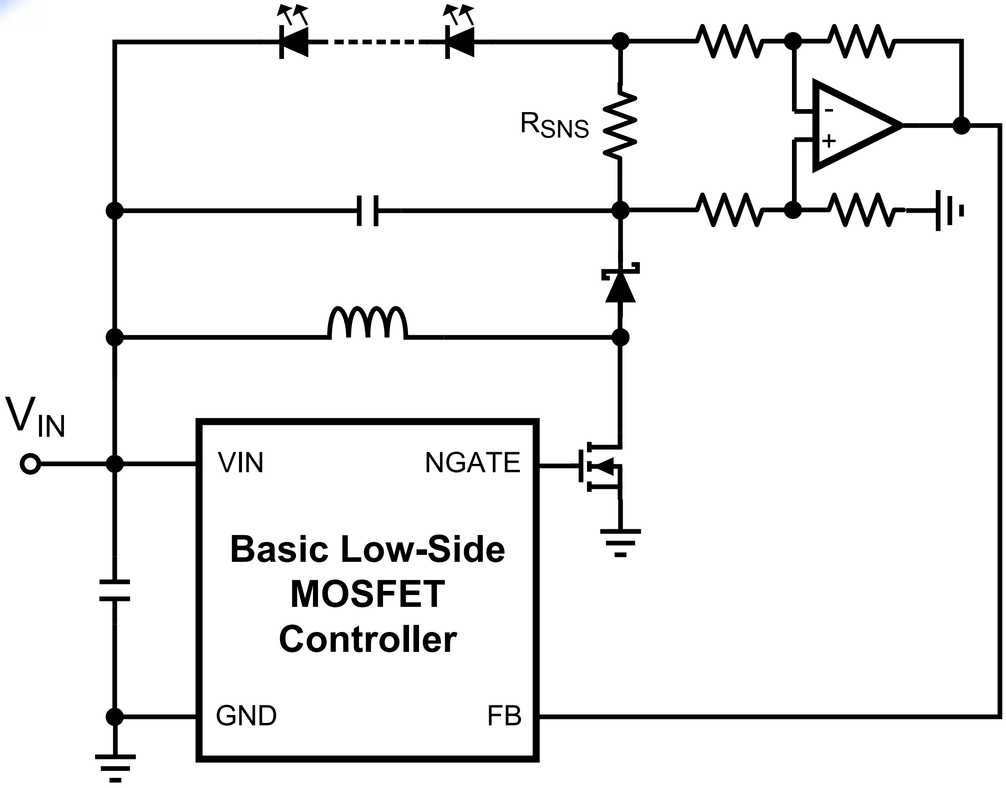
'Floating' Buck-Boost Regulator



$V_O = V_{IN} + V_F$

- **Uses only one inductor**
- **V_O is controlled WRT V_{IN}**
- **Requires high-side sensing for accurate I_F control**

Floating Buck Boost with High-side Sense



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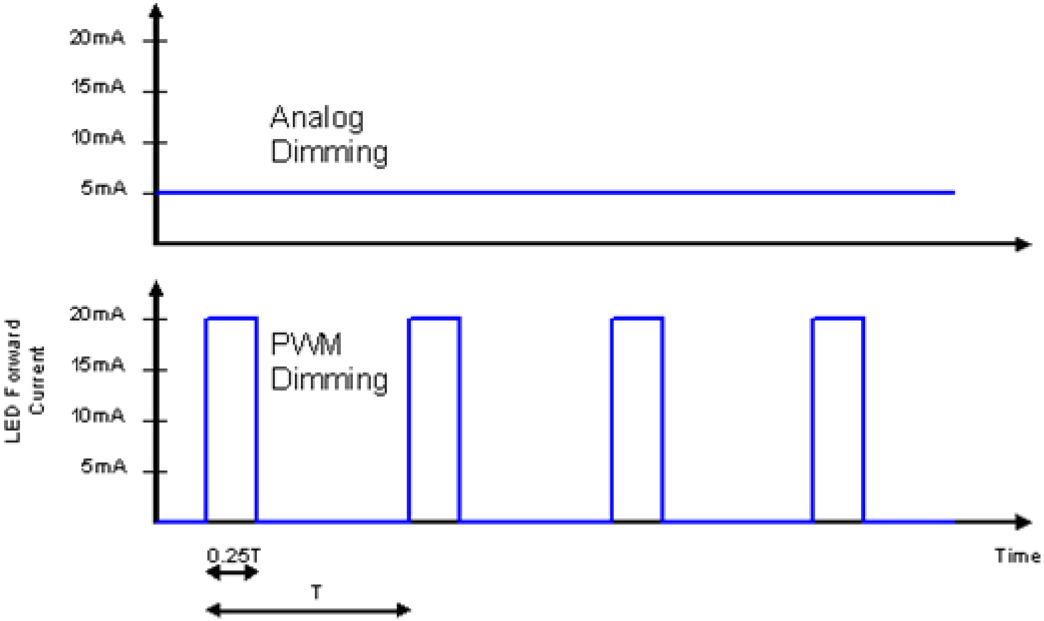
LED Dimming and Contrast Ratios

Adjusting Light Level with LEDs

- “Analog Dimming”
  - Linear adjustment of current through LEDs
  - Causes shift in peak and dominant wavelength in monochromatic LEDs
  - Causes shift in Correlated Color Temperature (CCT) in white LEDs
  - Difficult to optimize driver efficiency
- “Digital Dimming” (PWM Dimming)
  - Drive at only one current level
  - Turn LEDs on and off at > 120Hz
  - Human eye integrated and averages light above this frequency

PWM Dimming Control

- **PWM signal (EN/SD pin, FET, or special PWM pin)**
  - **"Average" Brightness proportional to Duty Cycle (D): $D = t_{ON} / T$**



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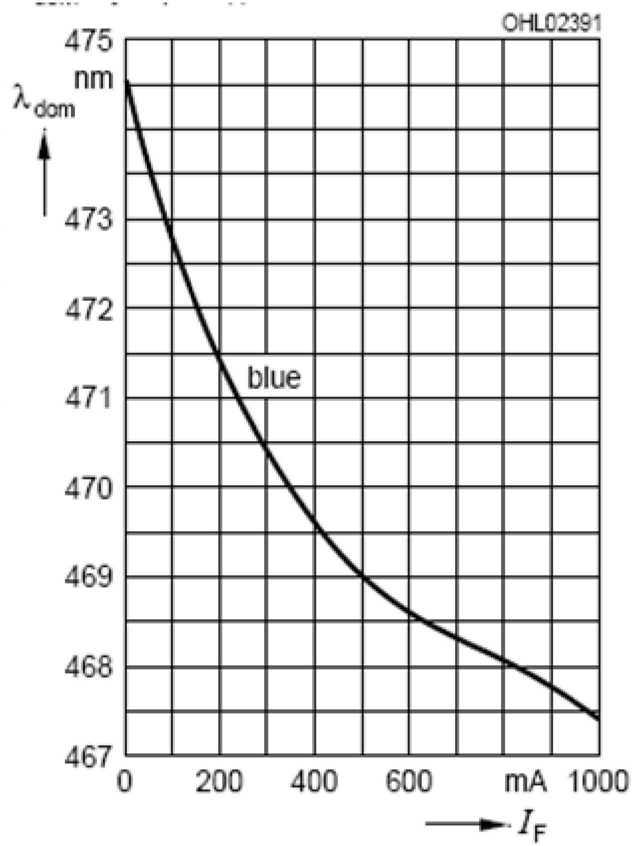
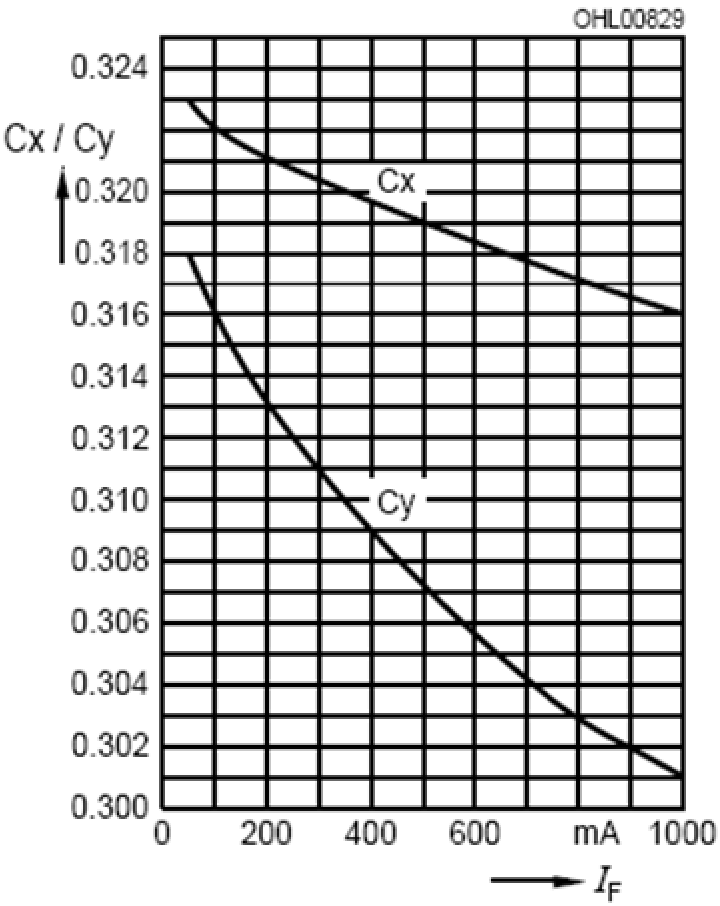
Controlling Color

- Colored LEDs shift their peak/dominant wavelength as I_F changes
- Requires control of I_F and Δi_F
- Accuracy of I_F is highly dependent on the application

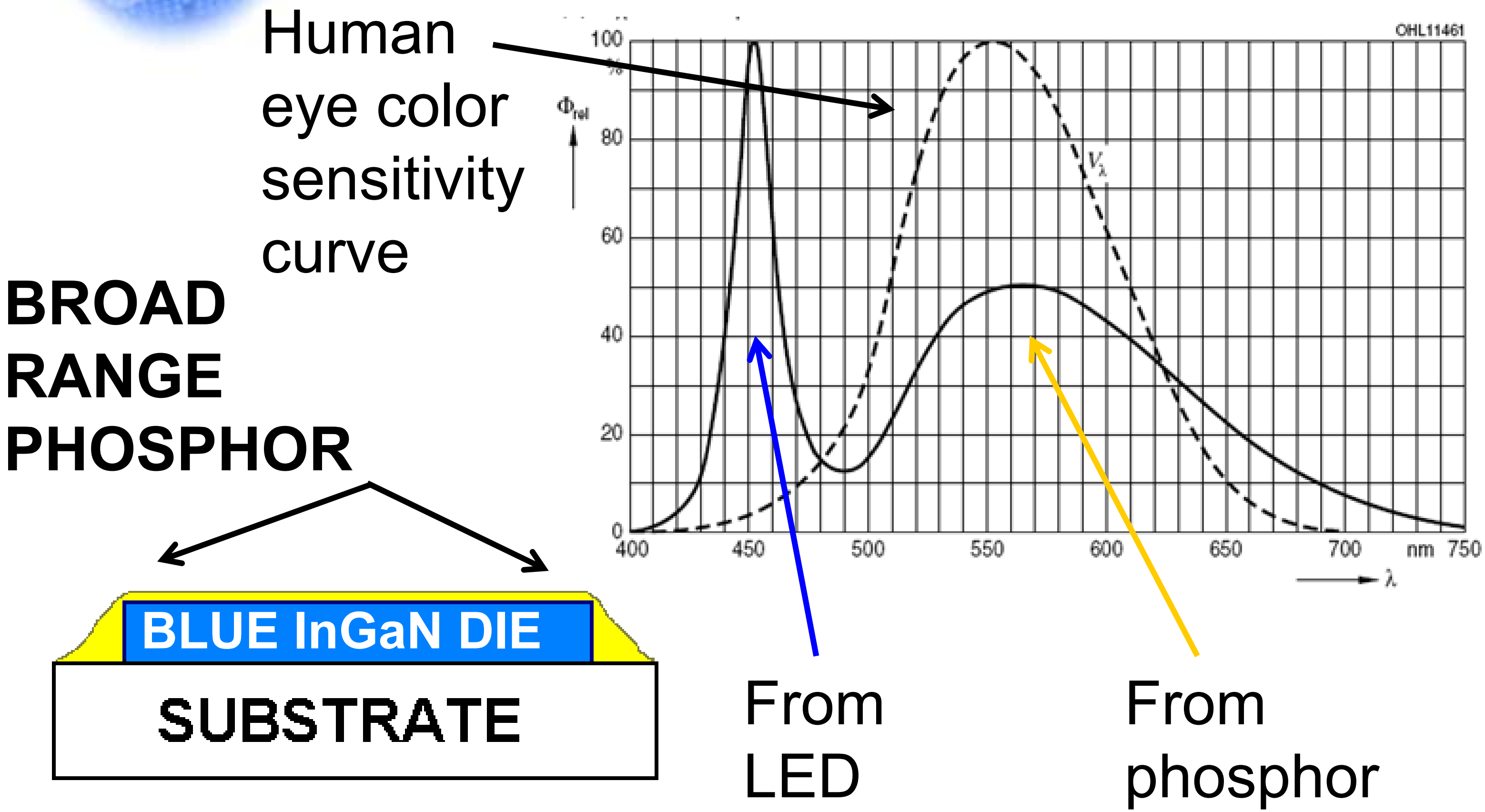


Controlling CCT

- CCT provides the basis for “cool” white (more blue) and “warm” white (more red.)
- CCT shifts with I_F
- Much easier to see than with colored LEDs



White LED Structure

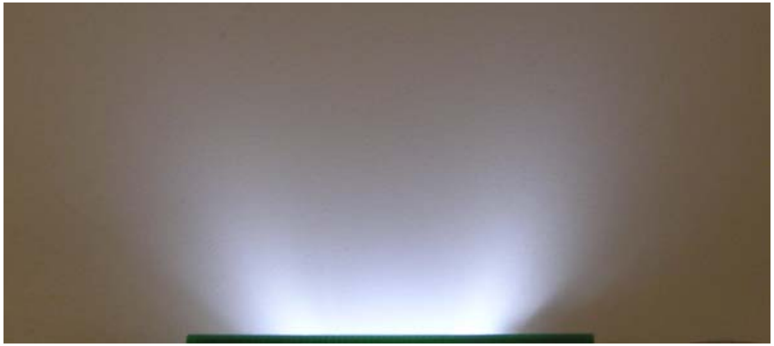


CCT Shift

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 with Switching Regulators

- **Use buck regulator whenever possible**
- **Only the buck can eliminate the output capacitor***
- **No RHP zero means fastest control loops (when using clocked regulators)**
- **Easy implementation of hysteretic and controlled on-time (COT) control**
  - **Even faster loops!**

Contrast Ratio

- 1 : Wishful Thinking
- Contrast ratio is highly dependent on the external components
- Therefore, it is highly susceptible to specmanship
- One definition of contrast ratio is $1/D_{DIM(MIN)}$, where $D_{DIM(MIN)} = 2 / f_{SW}$
  - Circuit must be on DCM/CCM boundary

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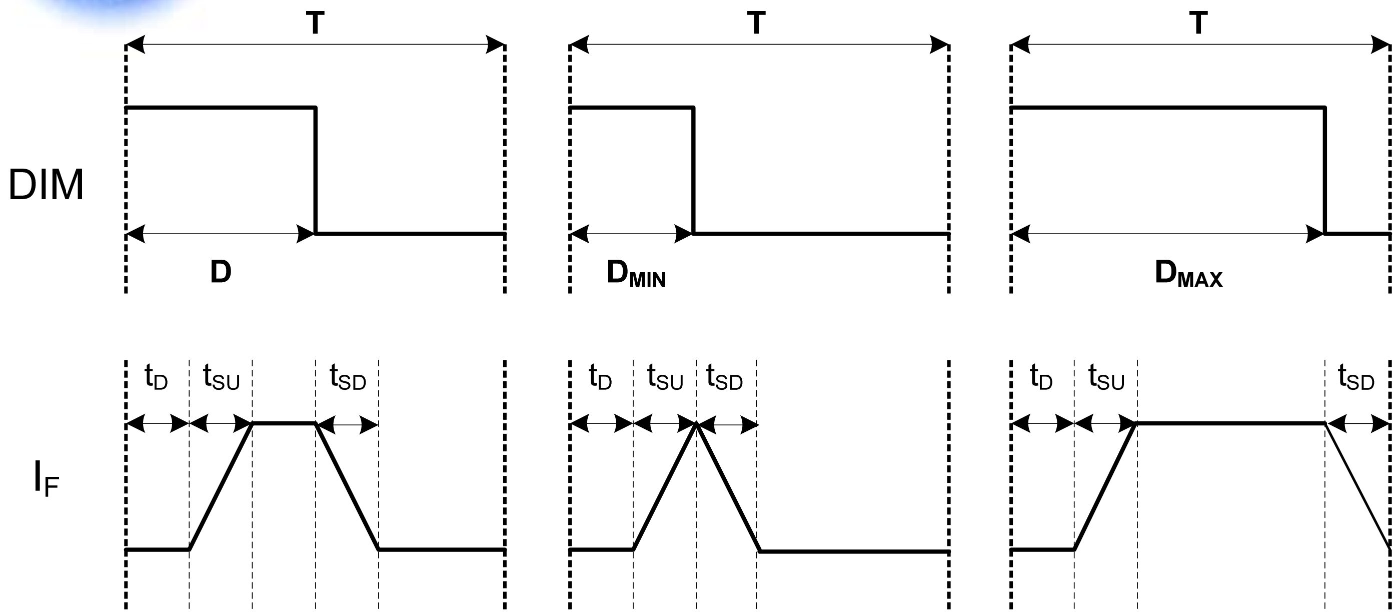
Frequency and Duty Cycle Limits



$$T = \frac{1}{f_{PWM}}$$

$$D_{MIN} = \frac{t_D + t_{SU}}{T}$$

$$D_{MAX} = \frac{T - t_{SD}}{T}$$

Rise and fall times where I_F is between 0 and 100% cause further error

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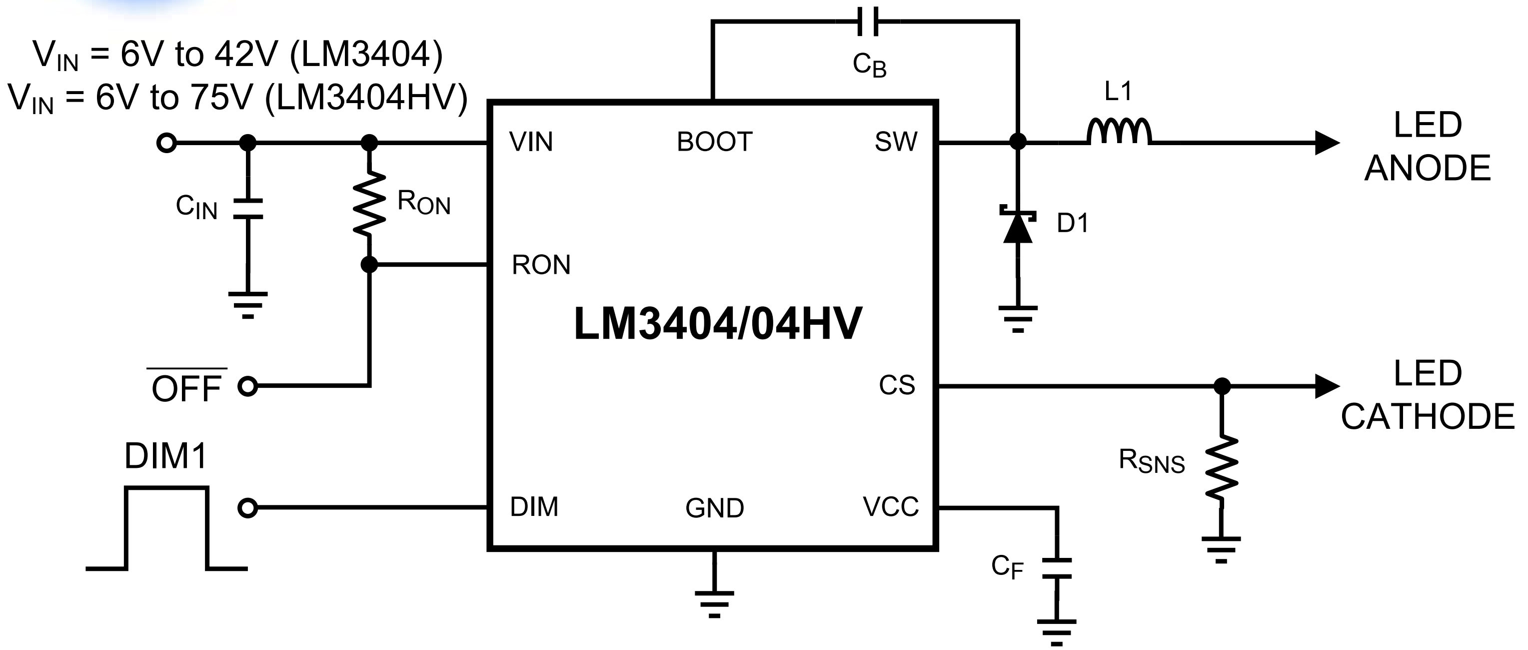
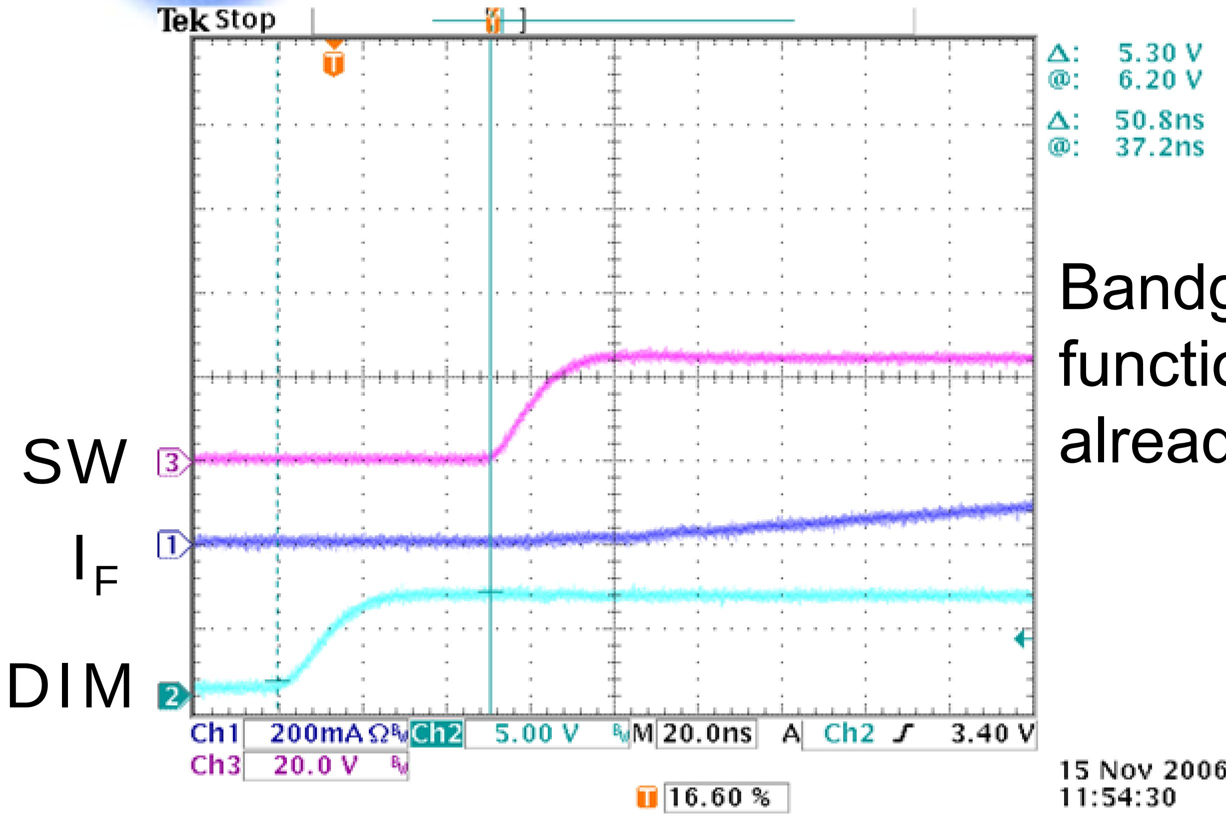
LM3404 Eval Board



Drives a 1W white (InGaN) LED at 1A from 24V

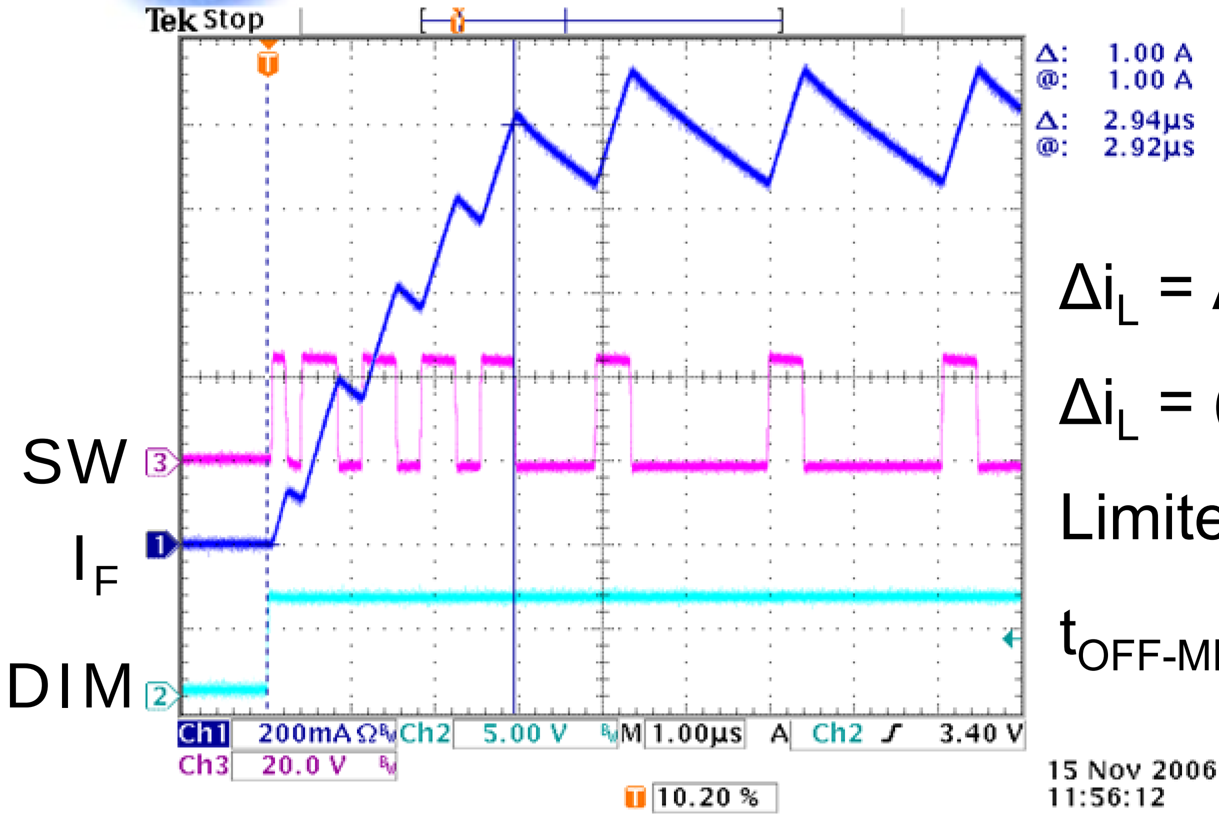
LM3404 Delay, t_D



t_D = 51 ns

Bandgap, analog functions were already powered

LM3404 Slew Up, t_{SU}



t_{SU} = 3 µs

$\Delta i_L = \Delta i_F$ (no C_O)

$\Delta i_L = (V_{IN} - V_O) / L$

Limited by $t_{OFF\text{-}MIN}$

$t_{OFF\text{-}MIN}$ = 300 ns

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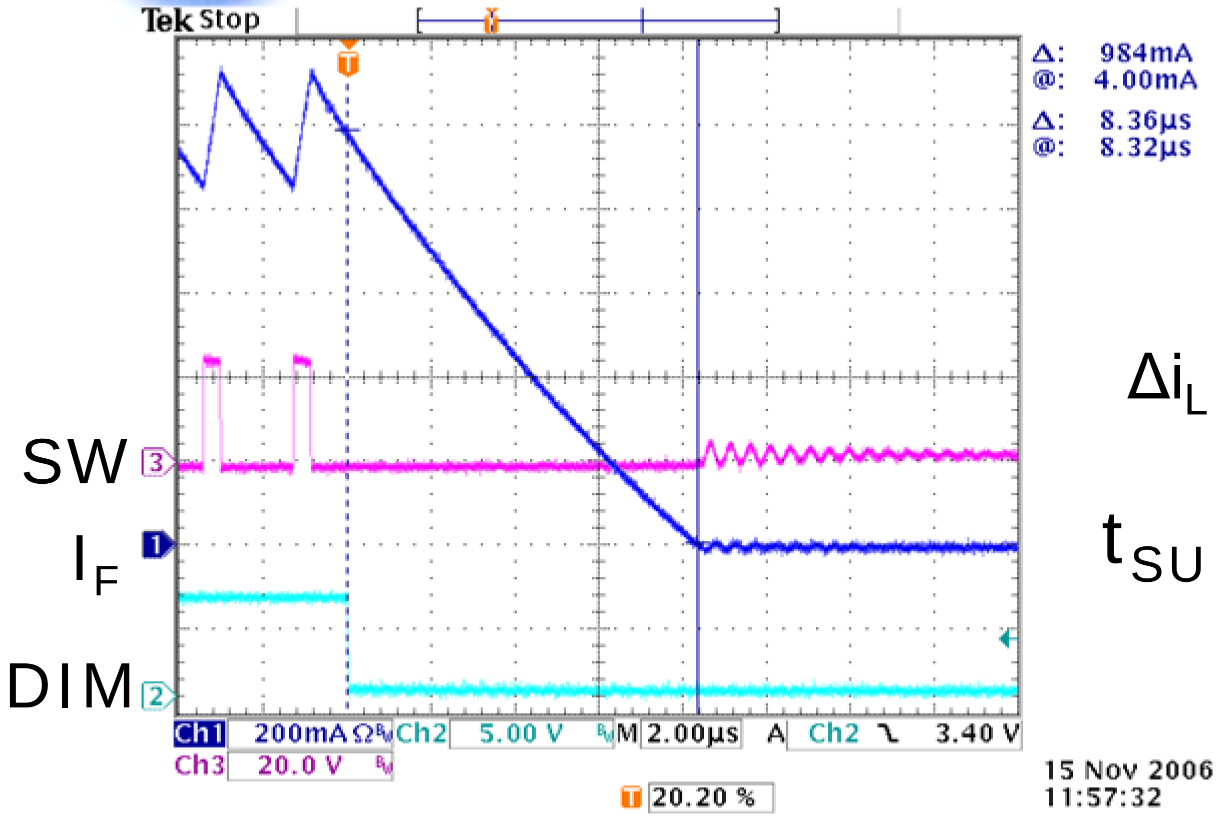
LM3404 Slew Down, t_{SD}



$$\Delta i_L = -V_O / L$$

$$t_{SU} = 8.4\ \mu s$$

Calculate the Contrast Ratios

f_{DIM} = 500 Hz, T_{DIM} = 2 ms

- **LM3404**
- **$t_D + t_{SU}$ = 3.05 µs**
- **D_{MIN} = 3.05 / 2000 = 0.001525**
- **CR = 1 / D_{MIN} = 655 : 1**

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**
- **Generation of white light from RGB in backlights, video projectors**
- **Machine vision and industrial inspection**
  - **Fast slew rates for light pulses that sync to sensors and cameras**
- **Loss of efficiency due to the transitions**
- **Usually requires a parallel dimming FET**

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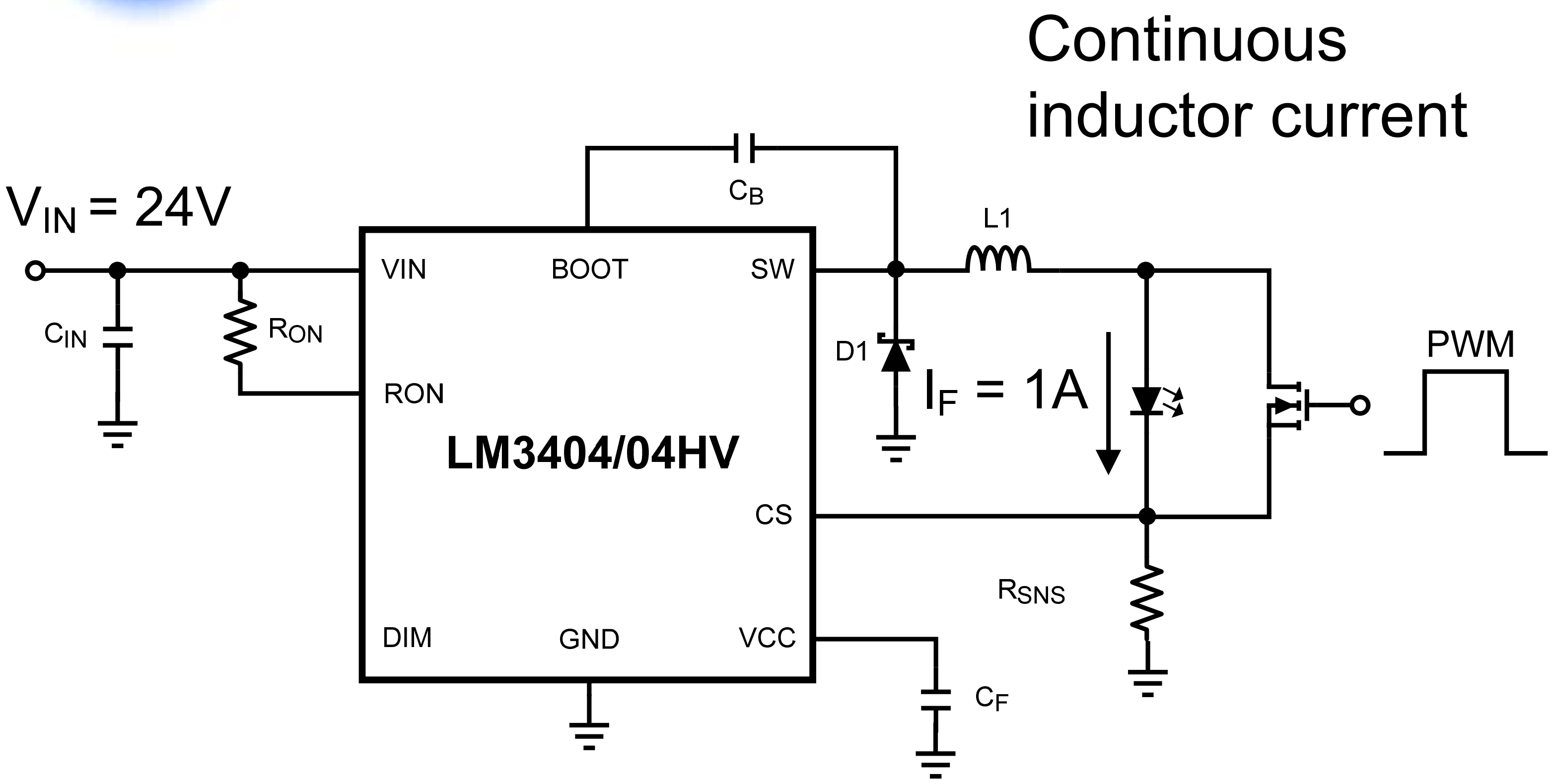
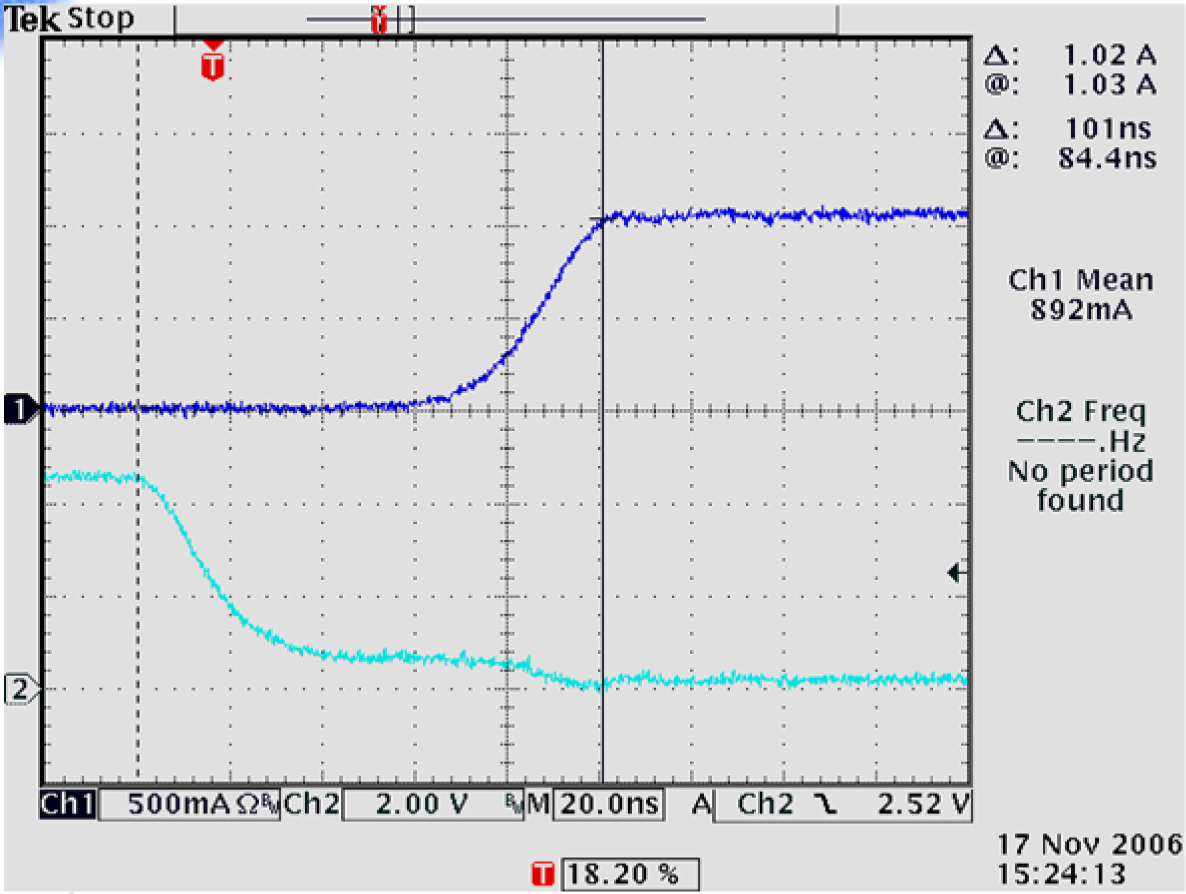
Parallel FET Dimming



Parallel FET Results



I_F

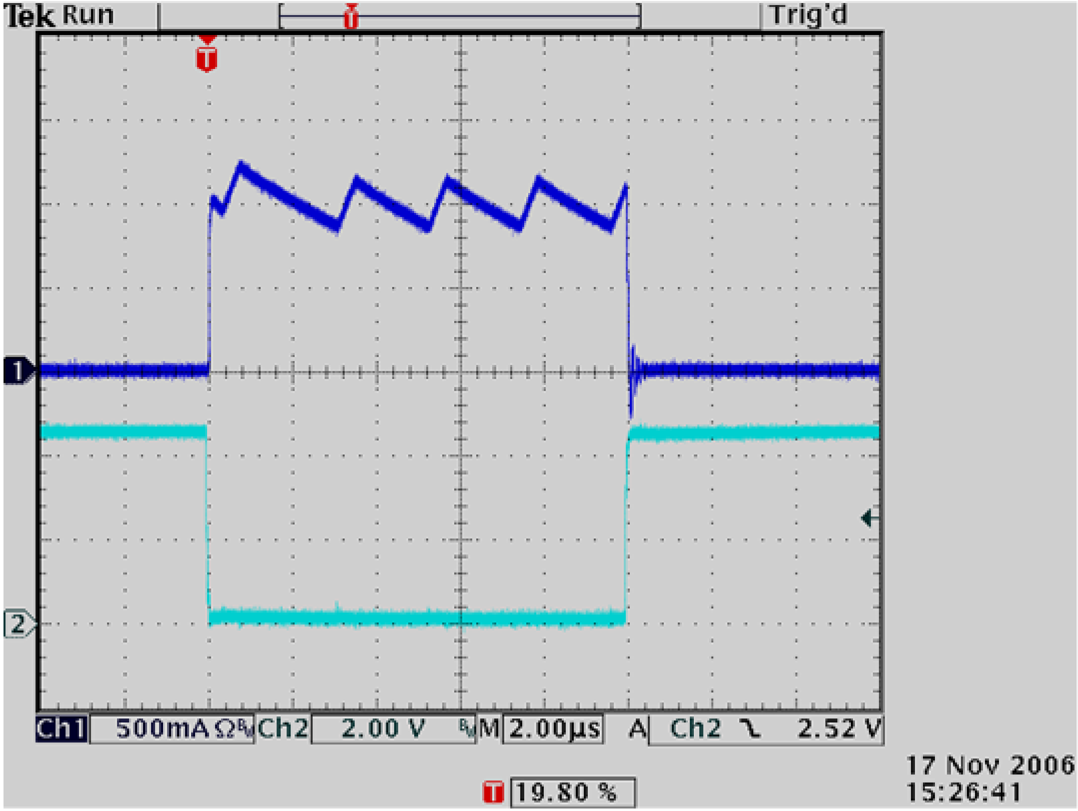
FET

GATE

Parallel FET Results

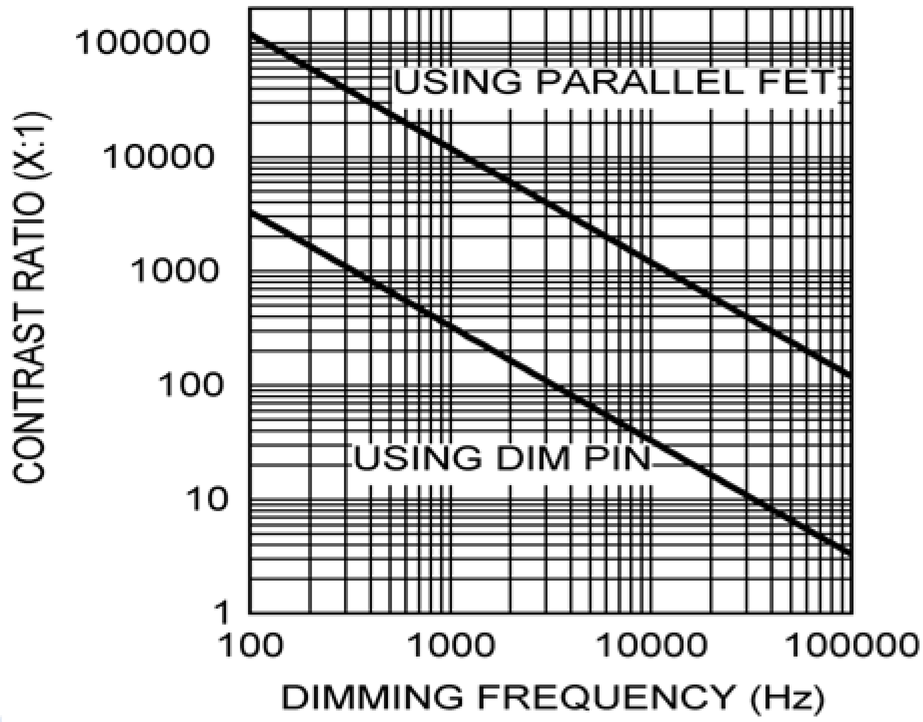
I_F

FET



CR Vs. f_{DIM}

- **Circuit parameters placed a limit on the minimum dimming on-time, $t_{MIN} = D_{MIN} \times f_{DIM}$**



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New LED Driving Tools

LED.National.com

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Easy Design with Online Tools

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Deutsche Version

LED Product Information

New Products:

- **LP5520** RGB Backlight LED Driver
- **LP5521** Programmable Three Channel LED Driver
- **LP5522** Programmable LED Driver
- **LP55281** Quad RGB Driver
- **LM3509** High Efficiency Boost for White LED's and/or OLED Displays with Dual Current Sinks and IC Compatible Brightness Control
- **LM3402/LM3404** 0.5A/1.0A Constant Current Buck Regulator for High Power LED Drivers, V_{IN} Range from 6V to 42V
- **LM3402HV/LM3404HV** 0.5A/1.0A Constant Current Buck Regulator for High Power LED Drivers, V_{IN} Range from 6V to 75V
- **LM5022** 60V Low Side Controller for Boost and SEPIC regulators, Allows Control of an External Mosfet to Deliver Higher Current to LEDs
- **LM2754** 800mA Switched Capacitor Flash LED Driver with Time-Out Protection
- **LM3405** 300kHz/1.6MHz 1A Constant Current Buck Regulator for LED Driver
- **LM2754** 800mA Switched Capacitor Flash LED Driver with Time-Out Protection
- **LM27965** Dual Display White LED Driver with I^2C Compatible Brightness Control
- **LM27966** White LED Driver with I^2C Compatible Interface

LED Product Tables:

- High Brightness LED Drivers
- Low Power White-LED Drivers
- Lighting Managment Units (LMU)

NEW! LED Lighting Management Solutions Selection Guide (pdf 980KB)

LED Reference Design Library
Proven designs for various lighting applications, including automotive, general illumination, flashlights, and architectural lighting

Other WEBENCH Designs:

- LM2750 Low Noise Regulator Switched Capacitor Boost Regulator
- LM3557 Step-Up Converter for White LED Applications Switched Cap Converter

Online Education:

- Online Seminar: Lighting Solutions for Portable Devices

Press Releases:

LED WEBENCH

LED Selection

Select from the list below or enter your custom values:

V_f 3.0 V　I_f 0.35 Amps　**Manufacturer:** ALL

Vendor	Family	Part Number	Color	Vf	Io	Lu Ph/V	View
OSRAM	Power TOPLED®	LB-E65G	blue	3.4	0.03	1.2	
OSRAM	Power TOPLED®	LT-E65G	green	3.4	0.03	3.95	
OSRAM	Power TOPLED®	LW-E65G	white	3.4	0.03	4	
OSRAM	Power TOPLED®	LA-E67S	amber	2.15	0.05	2.95	

Configuration and Options

V_{in} Min 25.0 V　Number of LEDs: - Series 1　V_{LED} 3.0 V

V_{in} Max 42.0 V　- Parallel 1　I_{out} 0.35 Amps

Click here for full version of WEBENCH LED Designer

Show Recommended Power LED ICs

LED Lighting

LED Lighting Overview
Regardless of type, color, size, or power, all LEDs work best when driven with a constant current. LED manufacturers specify the characteristics (such as lumens, beam pattern, color) of their devices at a specified forward current (I_F) not at a specific forward voltage (V_F). Most power supply ICs are designed to provide constant voltage outputs over a range of currents, hence it can be difficult to ascertain which parts will work for a given application from the device datasheet alone. With an array of LEDs, the main challenge is to ensure that every LED in the array is driven with the same current. Placing all the LEDs in a series string ensures that exactly the same current flows through each device.

Low-Power LEDs
Low-power LEDs are ideal for lighting portable electronics because they are efficient, easy to drive, small, thin, robust, and low noise. When running off a Lithium-Ion battery (typically 3.7V output voltage), each low-power LED requires up to 4V at 30 mA. To operate more than one LED for a lighting solution, an LED driver is needed to boost the voltage and regulate the current to optimize LED output.

For low-powered LEDs, National offers LED drivers for both parallel and series solutions. Parallel drivers with built-in, actively-matched, high- and low-side current sources, high efficiency, and a low total component count are available with inductive-boost converters, switched-capacitor boost converters, or no boost at all. National's series of LED drivers with inductive-boost converters provide solutions that combine very high efficiency with low noise and a small footprint. All of these solutions are optimized to drive 2 to 10 LEDs, and are available in the industry's smallest packaging: tiny micro-SMD BGA and versatile LLP (Leadless Leadframe Package) and CSP-leadless

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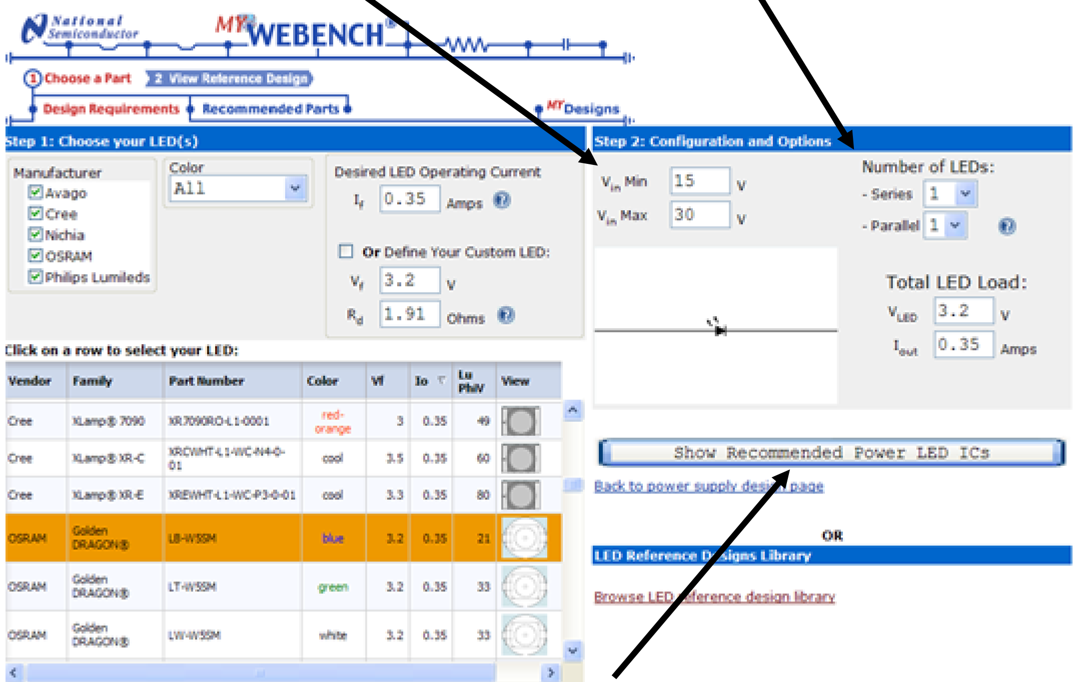
Step 1 - Enter Design Inputs

Enter input voltage range

Enter Number of LEDs

Narrow LED choice by vendor and/or color

Select an LED from the list



Show Recommended Parts

Step 2 - Choose an LED Driver

Choose part

Help ヘルプ

National Semiconductor MY WEBENCH®

1 Choose a Part | 2 Create a Design | 3 Analyze a Design | 4 Build It! | 5 Test It! | Demo

Design Requirements | Recommended Parts | MY Designs

Your Design Specifications

Input Voltages	Output	#1
VinMin=15.0V	Vout=	3.2V
VinMax=30.0V	Iout=	0.35A

Solution Selector found 10 solutions.

Recommended Devices

Switching Regulator

High efficiency regulator

LM3402

Start Your Design

Topology	BUCK
Max Current	0.5 A
Typical Efficiency	91%
On/Off Pin	Y
Error Pin	N
Price	$1.25
Frequency	1800 kHz

[Switching Regulators]

- Circuit Calculator - Reference Design - Webtherm Simulation - Electrical Simulation - Buildit

Recommended Switching Regulators - BUCK Topology

#	Product Folder	Create	WEBENCH Tools	Est. Price	Typ. Eff.	On/Off	Err. Pin	Sync	Soft Start	AdjIpk	Design Considerations	Freq. kHz	Max Curr.
1	LM3402	Start Your Design		$1.25	91%	Y	N	N	N	N		1800	0.5A
2	LM3402HV	Start Your Design		$1.50	91%	Y	N	N	N	N		1800	0.5A
3	LM3404	Start Your Design		$1.50	92%	Y	N	N	N	N	Available in SO-8 and PSOP-8	1800	1.0A

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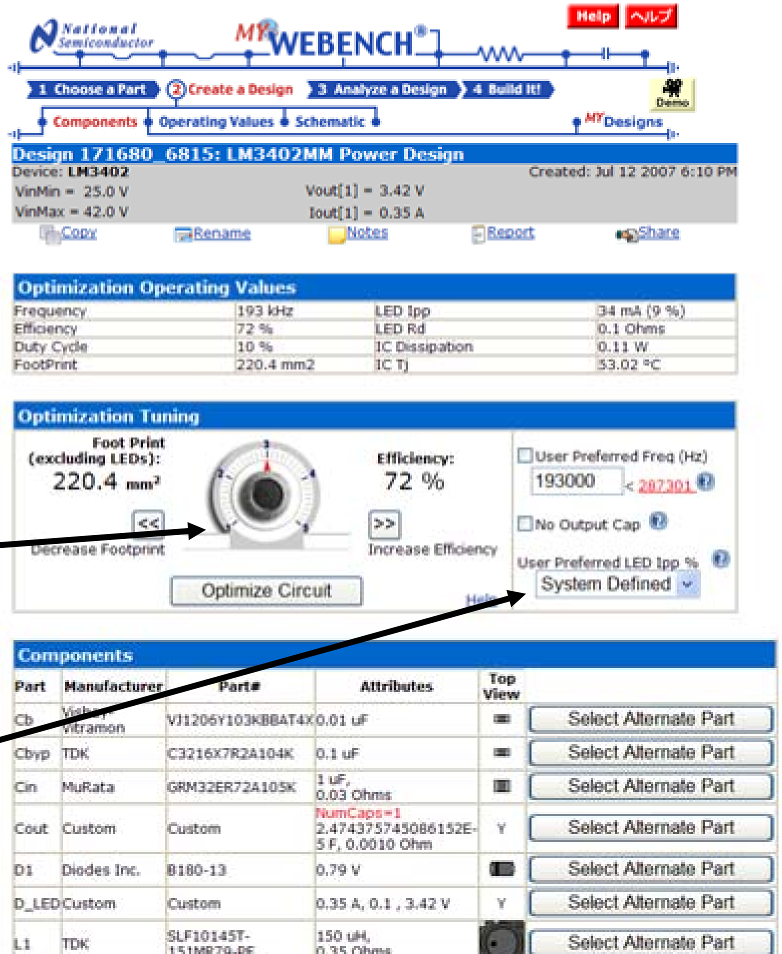
Step 3 – Optimize and Customize

Key operating values:
Frequency,
Efficiency
Peak to Peak I_{LED}
Temperature

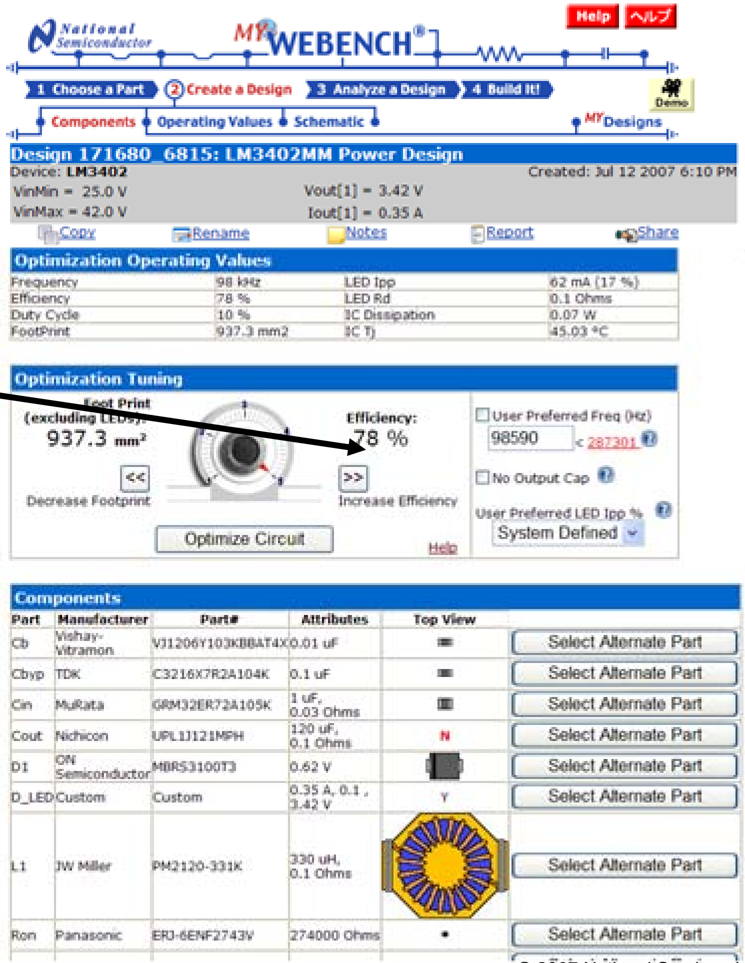
Optimization knob:

Customize design for:
No output cap
Specify peak to peak LED ripple



Optimize for Efficiency

Optimization for efficiency:
Lowers switching frequency, emphasizes low component power dissipation



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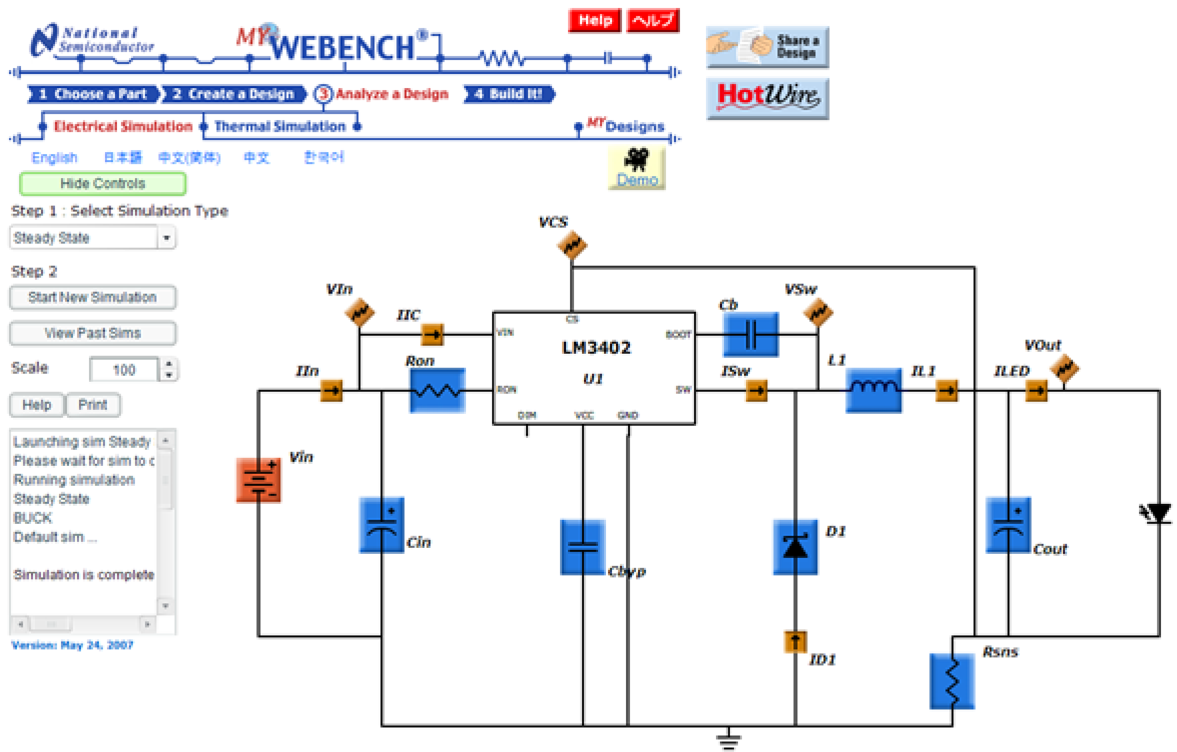
Step 4 - Simulate Electrical Behavior

Spice simulation includes:
Steady state
Input transient
PWM dimming
Startup



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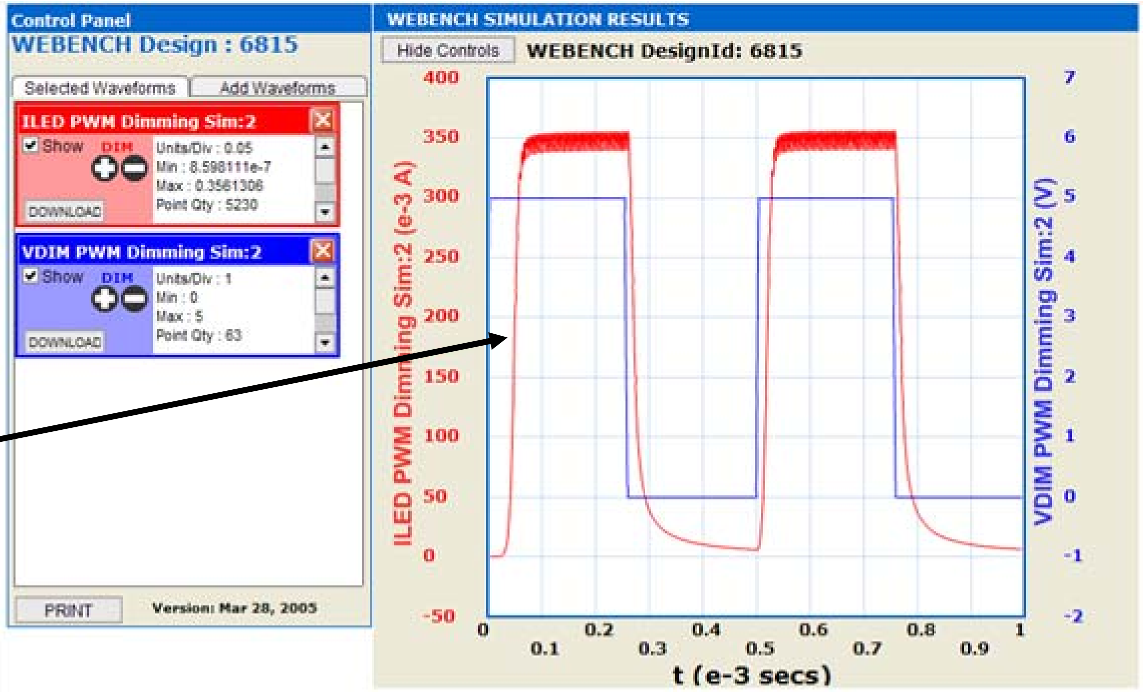
View Waveforms

Add/delete waveforms

Click and drag mouse to zoom in on plot



Build It!

- **Latest addition to LED WEBENCH® for LM3402/02HV and LM3404/04HV**
- **Generic evaluation board accepts a wide variety of external components**
- **User orders and receives a kit with blank PCB and all external components as selected through LED Webench**
- **Simply solder, connect to LEDs, and go**
- **Note: LEDs are not included**

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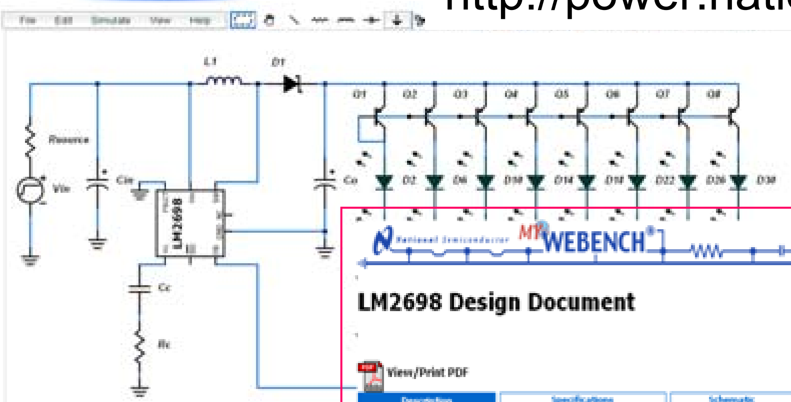
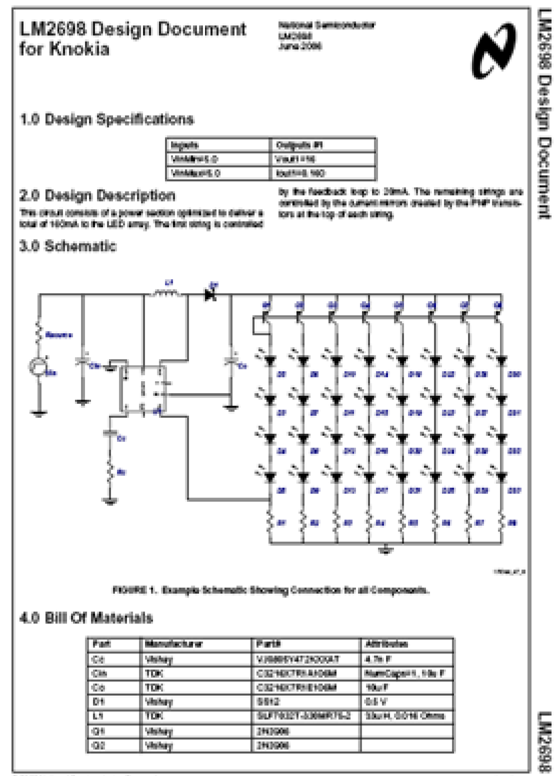
LED Reference Design Library

http://power.national.com



Modify

Customize



Custom datasheet of the resulting design

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