APPLICATION NOTES:

LED Electrical Driving Consideration

Introduction:

THE NEEDS OF A CONTROLLED CURRENT SOURCE

The IV curve for LED is similar to the IV curve for normal diode, except that it has steeper slope of I_f versus V_f in the high current region. As an example from the figure 1 below, variation of 0.1V supply voltage will cause the forward current differs by approximately 50mA. Since the luminous intensity of LED varies with forward current, this causes the relative intensity to vary by >10%. Therefore, LED circuitry should be designed to drive by controlled current source rather than controlled voltage source. With rapid advancement in semiconductor technology, various IC component suppliers are capable of producing constant current LED driver with output current accuracy +-3.5% between drivers and current matching smaller than 0.5% within driver (for LED driver with more than 1 output channel drive).

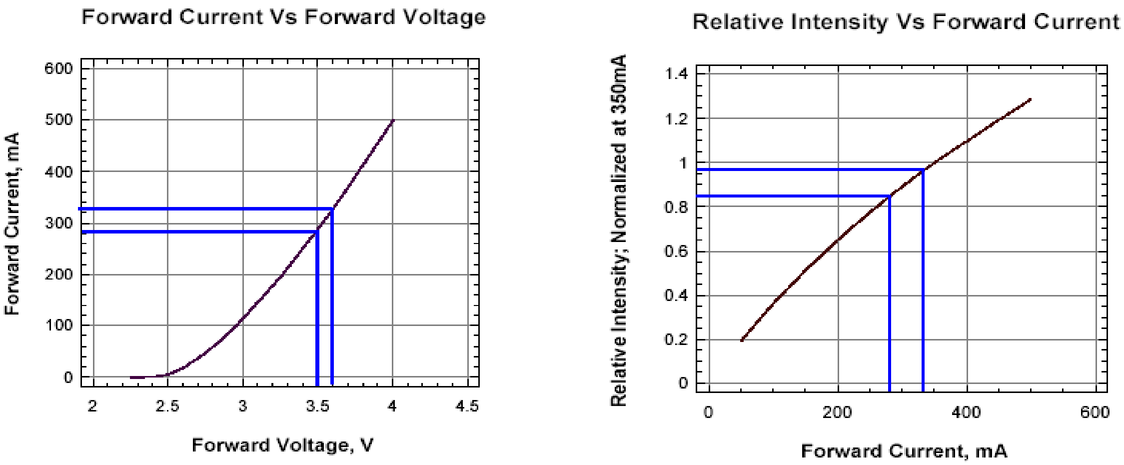


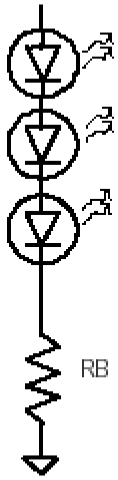
Figure 1– SPNovaLED InGaN White 350mA I_f vs V_f and I_v vs I_f Characteristic

GENERAL LED CIRCUIT DESIGN OVERVIEW

Current Limiting Method	Advantage	Disadvantage
Resistor (most common in existing automotive circuit design)	• Easy to design. • Inexpensive.	• It cannot control current accurately. • Current varies to some extent with supply voltage. • High power dissipation in the resistor especially on high power LED.
Linear Current Regulator	• Allow dimming through current control. • Linear control-loop circuitry accurately controlled the LED current.	• More expensive than simple resistive current limiter. • High power dissipation. • Might require heat sink for active pass device.
Switching Regulator Control	• Efficient operation over wide range of input voltage. • Able to regulate LED current precisely. • Allow dimming by PWM. • Lower power dissipation.	• More complex design. • More expensive compare to linear current supply. • Need to design for electromagnetic compatibility.

Current Limiting Method : Resistor

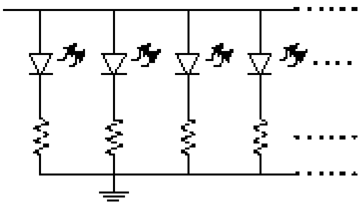
Series LED Drive Configuration :



Pros :
- Matching guaranteed with well regulated LED current
- Easy implementation with inductive boost
- Only 1 ballast element, most power efficient, ballast loss= $V_{Ballast}$ x I_{LED}

Cons :
- High output voltage drive required for long string of series LED. For low input voltage application, boost type regulator might be required
- A single defective LED would cause the whole string to fail

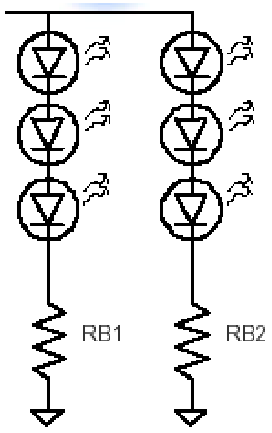
Parallel LED Drive Configuration :



Pros :
- Single defective LED will not cause all LED network to fail
- Lower output voltage drive required

Cons :
- Require regulated current source to ensure good matching, 1 for each LED
- More power loss compare to series implementation.
  Total ballast loss = N x $V_{Ballast}$ x I_{LED}

Parallel Strings of LEDs Configuration :



Pros :

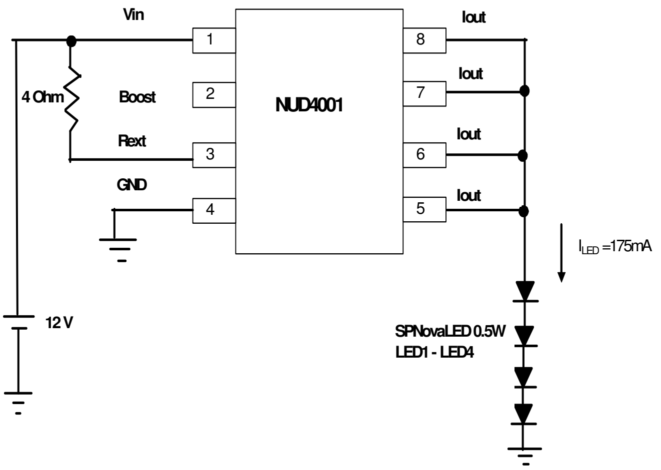
- Good for driving lots of LEDs
- Reduce the output voltage drive requirement compare to the series implementation for the same LED count.
- Lower power loss (ballast loss) compare to pure parallel implementation for the same LED count.

Cons :

- Only the 1st string has regulated current. Diode voltages set the current for all secondary strings.
- LED voltage mismatches would lead to brightness difference from one string to another.

Current Limiting Method : Linear Current Regulator

Figure 2, a typical LED circuit design using linear current regulator NUD4001 produce by On Semiconductor.



Features :

- Up to 30V operating range
- Adjustable output current level up to 500mA
- Minimum component count
- Suitable for automotive application in tail light, CHMSL and internal lighting application

Figure 2 – On Semiconductor NUD4001 linear current regulator

Current Limiting Method: Switching Regulator Control

A. SWITCHING POWER SUPPLY CURRENT CONTROL DRIVER

With ever demanding for higher brightness LED and higher power efficiency especially for portable power application, there is trend for major IC component manufacturer to introduce more advance switching LED current control driver with various functionality and better current matching/regulation.

When choosing the switching power supply LED current control driver, consideration should be taken on the supply input voltage level versus the output LED load voltage level. Basically the are 3 type of topologies for switching power supply :

1. Buck Regulator
   It can function if the input voltage always exceeds the sum of the maximum forward voltages of every LED in a string. It can reduce the output voltage to a lower level to minimize power loss.

2. Boost Regulator
   When the sum of all the forward voltages drop in a string will always exceed the maximum input voltage, a boost regulator is needed to amplify the output voltage to the required range in order to drive the LED network.

3. Buck/Boost Regulator
   When the input voltage might swing above or below the sum of all the forward voltage drop in a string, then a buck/boost regulator should be use to drive the LED network.

Various LED driving circuitry is depicted as below, please refer to respective IC manufacturer for detail design consideration when using their LED driver.

Switching Buck Regulator

Figure 3, a high power LED driving circuit design using National Semiconductor LM3402 0.5A constant current buck regulator. V_{in} range from 6V to 42V (LM3402).

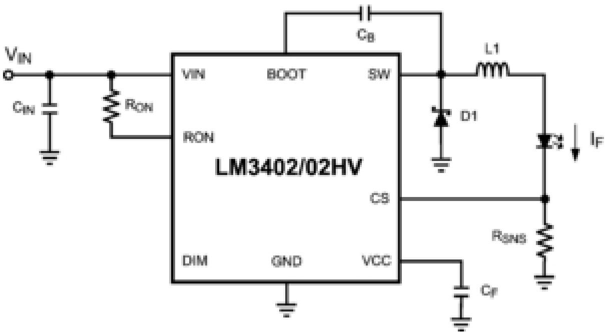


Figure 3 – LM3402, an example of buck regulator

Figure 4, another LED circuit design using Texas Instrument bq24105. The bqSWITHER series can achieve 10% current regulation accuracy for 100mV to 200mV sensing resistor voltage.

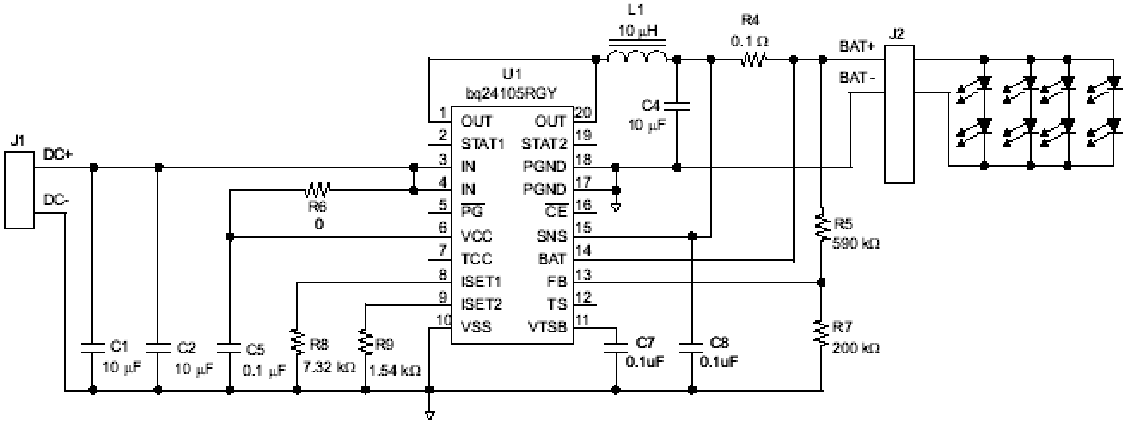


Figure 4 – bq24105, an example of buck regulator

A list of market commonly available buck regulator is as tabulated below :

Type	Supplier	Part Number	Vin (DC)	Vout(max, DC)	Iout (max, mA)
Buck	Exar	SP6652	2.7 to 5.5	5	1000
	Exar	SP6655	2.7 to 5.5	5	400
	STMicroelectronics	L6926	2 to 5.5	5	800
	Melexis	MLX10803	6 to 32	32	External
	National Semiconductor	LM3401	4.5 to 35	35	External
	National Semiconductor	LM3407	4.5 to 30	27	350
	National Semiconductor	LM3402	6 to 42	41	500
	National Semiconductor	LM3402HV	6 to 75	74	500
	National Semiconductor	LM3404	6 to 42	41	1200
	National Semiconductor	LM3406	6 to 42	37	1500
	National Semiconductor	LM3406HV	6 to 75	67	1500
	National Semiconductor	LM3405A	3 to 22	21	1000
	National Semiconductor	LM3404HV	6 to 75	74	1500
	National Semiconductor	LM3489	4.5 to 35	Adjustable	External
	Sipex	SP6137	3 to 20	3 to 15	External
	STMicroelectronics	L6902	8 to 36	34	1000
	Zetex	ZXLD1350E5	9 to 30	30	350
	Zetex	ZXLD1350	7 to 30	30	350
	Zetex	ZXLD1360	7 to 30	30	1000
	Zetex	ZXLD1362	6 to 60	60	1000
	Zetex	ZXLD1320	4 to 18	18	1500
	Zetex	ZXLD1352	7 to 30	30	350
	Zetex	ZXLD1356	6 to 60	60	550
	Zetex	ZXLD1366	6 to 60	60	1000
	National Semiconductor	LM2734	3 to 20	18	1000
	Sipex	SP7601	4.5 to 29	29	External
	Catalyst	CAT4201	6.5 to 20	32	350

Switching Boost Regulator

Figure 5 below shows a typical switching boost regulator circuit design using Linear Technology LT3466-1, white LED driver and boost converter. It can drive up to 10 white LEDs from a 3.6V supply. It allows +-4% current programming accuracy.

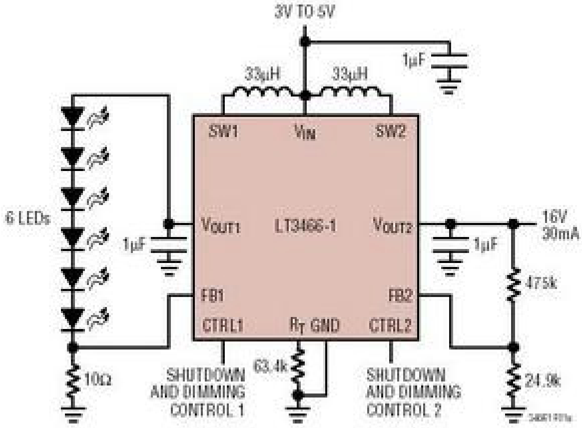


Figure 5—LT3466-1, an example of boost regulator

Figure 6, another switching boost regulator design using On Semiconductor NCP5010, 500mW boost converter for white LED. It featuring 2.7V to 5.5V input voltage range. 84% Efficiency for 5 LEDs at 30mA and Vin =4.2V

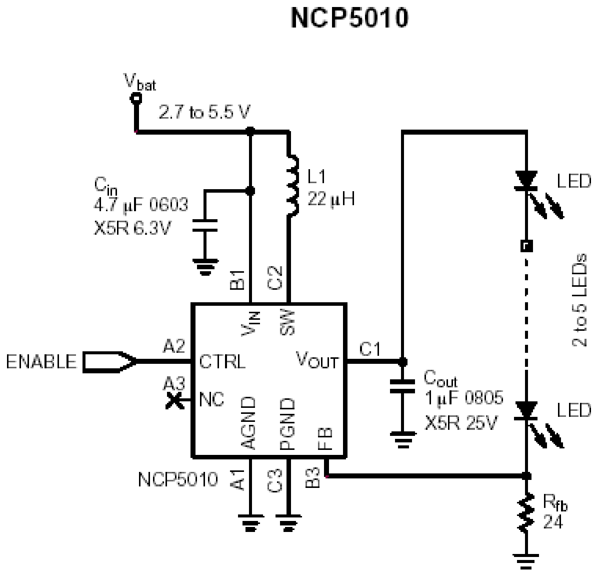


Figure 6—NCP5010, an example of boost regulator

A list of market commonly available boost regulator is as tabulated below :

Type	Supplier	Part Number	Vin (DC)	Vout(max, DC)	Iout (max, mA)
Boost	ON Semiconductor	NCP1422	1.0 to 5.0	5	800
	ON Semiconductor	NCP1450A	0.8 to 6.0	6	1000
	Exar	SP6641B	1.0 to 5.0	6	500
	Exar	SP6648	0.7 to 4.5	4	400
	Exar	SP7648	2.7 to 4.5	2.7 to 5.5	800
	Zetex	ZXSC310E5	0.8 to 8.0	8	1100
	Zetex	ZXSC400E6	1.8 to 8.0	8	1100
	Zetex	ZXLD1321	1.2 to 12.0	18	1000
	National Semiconductor	LM2623A	0.8 to 14	14	1000
	National Semiconductor	LM2700	2.2 to 12	17.5	1000
	National Semiconductor	LM3551	2.7 to 5.5	11	1000
	National Semiconductor	LM3553	2.7 to 5.5	19	1200
	STMicroelectronics	L6920	0.6 to 5.5	8	500

Switching Buck/Boost Regulator

Figure 7 below shows a typical switching buck/boost regulator circuit design using Linear Technology LTC3453, Synchronous Buck Boost High Power White LED Driver. It is optimized to drive up to 4 white LEDs at a combined current of 500mA from a single Li-Ion battery input. The regulator operates in either buck, boost or buck-boost mode, depending on the input voltage and LED maximum forward voltage.

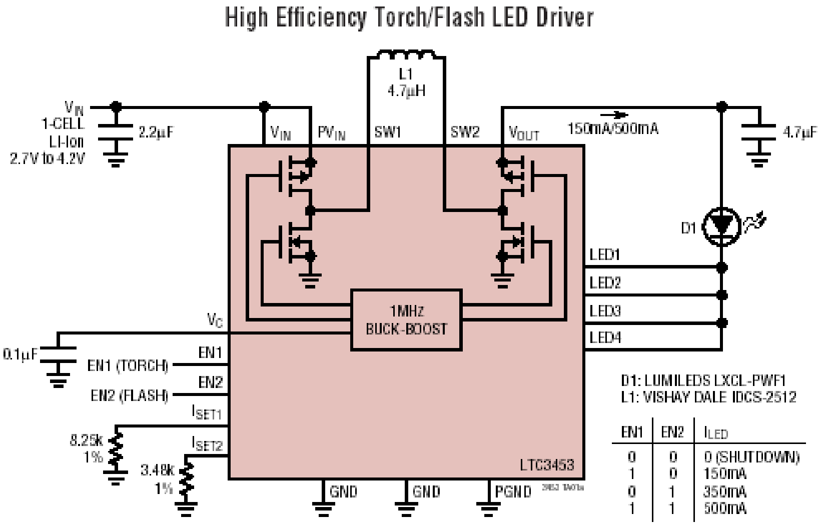


Figure 7-- LTC3453, an example of buck/boost topology regulator

Figure 8, another switching buck-boost regulator circuit design using MAXIM MAX1759, Buck-Boost Charge Pump Regulator. In the design below, the regulator biases white LEDs with 15mA current from a wide 1.6V to 5.5V voltage range.

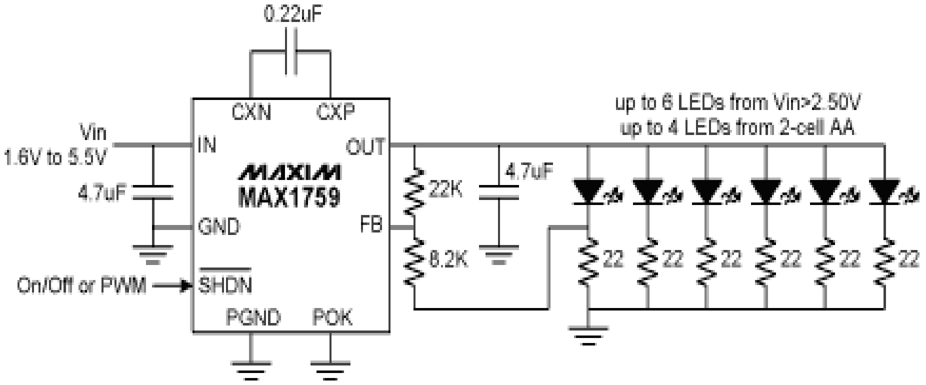


Figure 8—MAX1759, an example of buck/boost topology regulator

A list of market commonly available buck/boost regulator is as tabulated below:

Type	Supplier	Part Number	Vin (DC)	Vout(max, DC)	Iout (max, mA)
Buck/Boost	STMicroelectronics	STCF02	2.7 to 5.5	2.5 to 5.3	600
	STMicroelectronics	STCF03	2.7 to 5.5	2.5 to 5.3	800
	Zetex	ZXLD1322	2.5 to 15.0	15	700
	ON Semiconductor	NCP5030	2.7 to 5.5	5.5	1200
	ON Semiconductor	NCP3163	2.5 to 40	40	3000
	ON Semiconductor	NCP3065	3.0 to 40	40	1500
	National Semiconductor	LM3423	4.5 to 75	75	External
	National Semiconductor	LM3421	4.5 to 75	75	External
	Zetex	ZXLD1322	2.5 to 15	15	700

B. ADVANCE LIGHT MANAGEMENT UNIT (ALMU)

With the increasing popularity of LED application in various fields, especially in mobile handheld application and display backlighting, several major integrated circuit supplier have already starts to produce the advance light management IC. This ALMU not only regulate the LED current, but also provide various functionality to manage the brightness, sequence, and to synchronize the LEDs with audio input. The ALMU usually will come with an I^{2}C or SPI interface. This ALMU will further reduce the space required for LED control circuit and will simplify the circuit design effort. Several examples are depicted below. Please consult respective IC manufacturer's website for detail information.

National Semiconductor, LP3954, Advance Light Management Unit

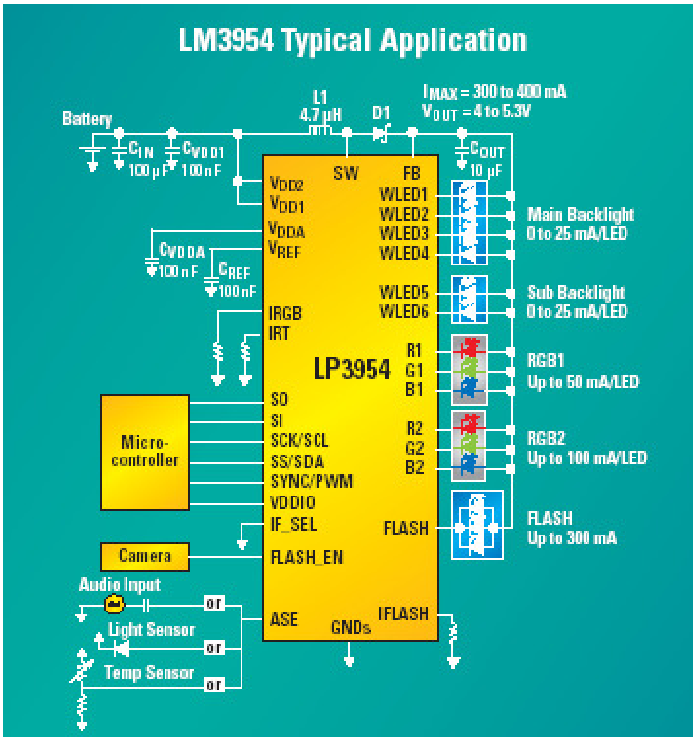


Figure 9—LP3954 Advance Light Management Unit

Features :

- Advance Light Management Unit for handheld product
- Audio synchronization for color/RGB LEDs
- High current driver for flash LED with built-in timing
- Six constant current white LED driver with 8-bit programmable adjustment
- SPI/I^{2}C compatible interface
- Possibility for external PWM dimming control

MAXIM MAX1707, Light Management Unit

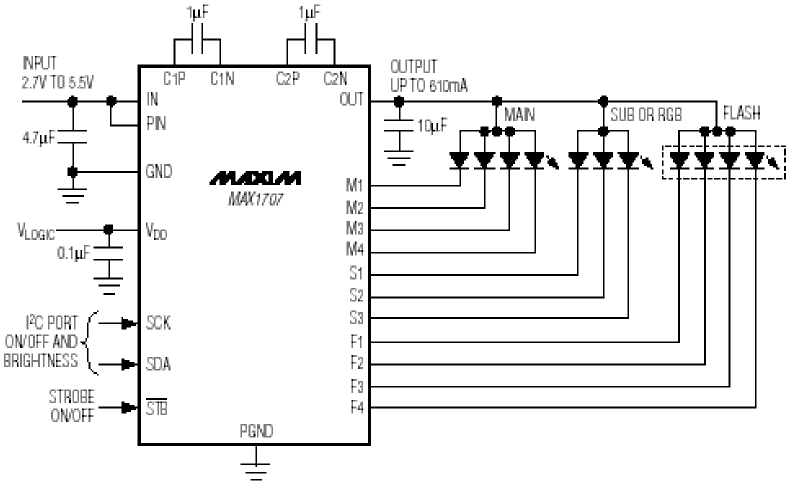


Figure 10 – MAX1707 Light Management Unit

Features :

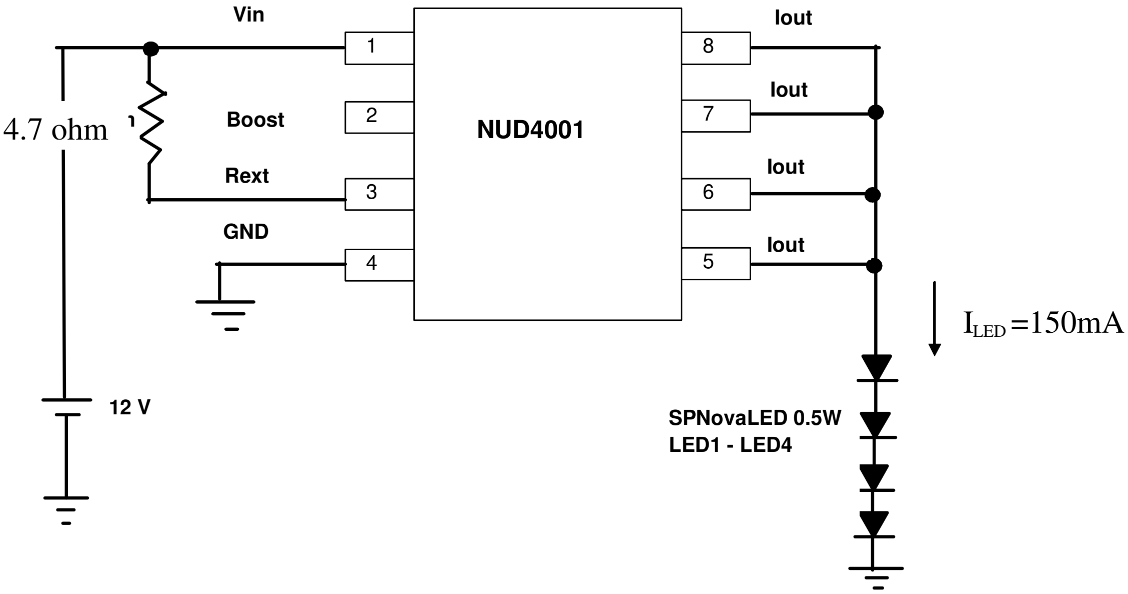
- The MAX1707 provides complete light management for main display backlight, sub-display backlight and white LED camera flash with regulated constant current up to total 610mA.
- An I2C serial port is used for on/off control and setting the LED currents in 32 linear steps.
- 0.3% LED current accuracy and matching.
- The I2C port provides 32k colors and programmable ramp up/down rates.
- The camera flash may be turned on/off by the I2C port

LED CIRCUIT PRACTICAL DESIGN GUIDE

For automotive/general lighting application, the most common input supply voltage would be 12V & 24V DC. The most common LED drive current level would be 120mA -150mA for SPNovaLED 0.5Watt and 320mA - 350mA for SPNovaLED 1Watt.

Two examples of reference design to drive a series of LEDs at Vin =12V, using On Semiconductor NUD4001, High Current LED Driver is depicted below. Please refer to NUD4001 datasheet for further technical details.

Reference Design 1 : Driving 4 Series Connected SPNovaLED 0.5Watt At Forward Current of 150mA , Supply Voltage, Vin = 12V



Bill Of Materials:

Part	Manufacturer	Part Number	Attribute
R_{ext}	Vishay	CRA06E0803472JRT1	4.7 Ohm resistor
NUD4001	On Semiconductor	NUD4001DR2G	High Current LED Driver
LED1-LED4	Dominant Semiconductor	NPR-SSS-XY2-1	SPNovaLED 0.5W Red

Several key parameters for NUD4001 are as follow :

1. V_{sense} = 0.7 V at T_j= 25 ºC
2. P $_{D\_control}$, Power dissipation for internal circuitry of NUD4001 is 0.055W at 12V input, 0.25W at 24V input.
3. Maximum power dissipation of NUD4001 is 1.13W.
4. It supplies constant LED current for varying input voltage up to 30V max
5. Output current level is defined by the resistor, R_{ext}

Electrical Design Guide:

1. LED current required, I_{LED} is 150mA
2. Resistor value for $R_{ext} = V_{sense} / I_{LED}$ = 0.7V/0.150 Ohm = 4.7 Ohm

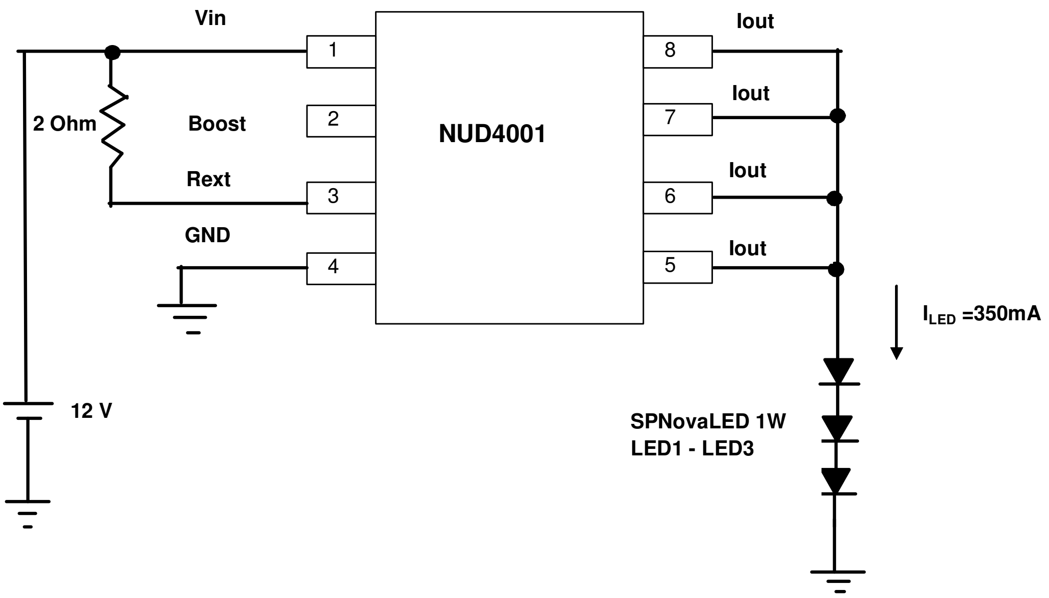
Thermal Design Guide :

Base on Dominant Semiconductor datasheet for SPNovaLED, for example NPY-SSS-XY2, the minimum forward Voltage Vf_{min} =1.9V, typical forward voltage V_{ftyp}= 2.2V. The power dissipation in the current regulator IC should be calculated for V_{fmin}, where the voltage drop across the current driver would be maximum. This will prevent the NUD4001 from being killed due to overheat.

V_{fmin} = 1.9V	**V_{ftyp} = 2.2V**
Total voltage across LED, V_{LED} = 1.9V x 4 = 7.6V	V_{LED} = 2.2V x 4 = 8.8V
Voltage drop across NUD4001, $V_{drop} = V_{in} – V_{sense} - V_{LED}$ = 12V – 0.7V -7.6V = 3.7V	V_{drop} = 12V -0.7V – 8.8V = 2.5V
Power dissipation across NUD4001, $PD_{\_driver} = V_{drop} \times I_{out}$ = 3.7V x 0.175A = 0.6475W	$PD_{\_driver}$ = 2.5V x 0.175A = 0.4375W
Total power dissipation, $PD_{\_total} = PD_{\_driver} + PD_{\_control}$ = 0.6475W + 0.055W = 0.7025W	$PD_{\_total}$ = 0.4375W + 0.055W = 0.4925W

Base on both case of Vf above, the total power dissipation is < 1.13W, which means the circuit above can be operated without overheating the NUD4001.

Reference Design 2 : Driving 3 Series Connected SPNovaLED 1 Watt At Forward Current of 350mA , Supply Voltage, Vin = 12V



Bill Of Materials:

Part	Manufacturer	Part Number	Attribute
R_{ext}	Vishay	CRCW12062R00FRT1E3	2 Ohm resistor
NUD4001	On Semiconductor	NUD4001DR2G	High Current LED Driver
LED1-LED3	Dominant Semiconductor	NPW-USD-AD-1	SPNovaLED 1W White

Several key parameters for NUD4001 are as follow :

1. V_{sense} = 0.7 V at T_j= 25 Deg C
2. $P_{D\_control}$, Power dissipation for internal circuitry of NUD4001 is 0.055W at 12V input, 0.25W at 24V input.
3. Maximum power dissipation of NUD4001 is 1.13W
4. It supplies constant LED current for varying input voltage up to 30V max
5. Output current level is defined by the resistor, R_{ext}

Electrical Design Guide:

1. LED current required, I_{LED} is 350mA
2. Resistor value for $R_{ext} = V_{sense} / I_{LED}$ = 0.7V/0. 350 Ohm = 2 Ohm

Thermal Design Guide :

Base on Dominant Semiconductor datasheet for SPNovaLED, NPW-USD-AD-1, the minimum forward Voltage Vf_{min} =3.0V, typical forward voltage V_{ftyp} = 3.6V.

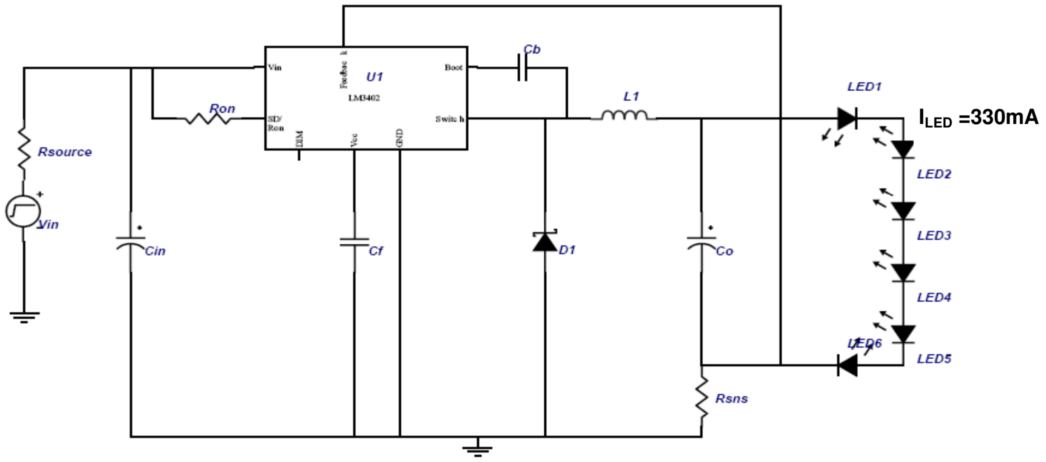
V_{fmin} = 3.0V	V_{ftyp} = 3.6V
Total voltage across LED, V_{LED} = 3.0 V x 3 = 9.0V	V_{LED} = 3.6V x 3 = 10.8V
Voltage drop across NUD4001, $V_{drop} = V_{in} – V_{sense}$- V_{LED} = 12V – 0.7V -9.0V = 2.3V	V_{drop} = 12V –0 .7V – 10.8V = 0.5V
Power dissipation across NUD4001, $PD_{\_driver} = V_{drop}$ x I_{out} = 2.3V x 0.350A = 0.805W	$PD_{\_driver}$ = 0.5V x 0.350A = 0.175W
Total power dissipation , $PD_{\_total} = PD_{\_driver} + PD_{\_control}$ = 0.805W + 0.25W = 1.055W	$PD_{\_total}$ = 0.175W + 0.25W = 0.425W

Base on both case of Vf above, the total power dissipation is < 1.13W, which means the circuit can be operated without overheating the NUD4001.

Please note that for the both reference design above, care should be taken to ensure minimum input voltage, $Vin_{min} > V_{sense} + V_{LED(Max)}$, in order to supply enough forward voltage drive for the LEDs.

Reference Design 3: Using National Semiconductor LM3402 (0.5A Constant Current Buck Regulator).

Driving 6 Series Connected SPNovaLED 1 Watt at Forward Current of 330mA, Supply Voltage, Vin = 24V (Please refer to National Semiconductor LED Reference Design Library : http://www.national.com/webench/ledrefdesigns.do for further details and circuit simulations.)



Bill Of Materials:

Part	**Manufacturer**	**Part #**	**Value**
Cb	Vishay	VJ0805Y103KXXAT	10nF
Cf	Vishay	VJ0805Y104KXXAT	100nF
Cin	TDK	C3225X7R1H225M	2.2uF
Co	TDK	C3225X7R1E475M	4.7uF
D1	Central Semiconductor	CMSH1-40M	0.5V
L1	TDK	SLF7045T-470MR75	47uH, 0.15 Ohm
Ron	Vishay	CRCW08054873F	487k Ohm
Rsns	Panasonic	ERJ6BQFR56V	0.56 Ohm
U1	National Semiconductor	LM3402	
LED1-LED6	Dominant Semiconductor	NPW-TSD	SuperNovaLED 1 W

LED DRIVER

The following is a list of integrated circuit suppliers that produce LED driver/LED Management device or regulator that can be configured to drive LED circuits. Please refer to their website for detail design consideration and specification. (Note : The name of the IC manufacturers below is directly hyperlink to their respective website)

IC Supplier

Analog Devices
Fairchild Semiconductor
Holtek Semiconductor Inc.
Infineon
Intersil Corporation
Linear Technology
Maxim Integrated Products
Micrel Semiconductor
MICRO ANALOG SYSTEMS
MicroChip
Microsemi Corp.
Mitsubishi Semiconductor
National Semiconductor
SIPEX
SUPERTEX
STMicroelectronics
Texas Instruments
ZETEX

With the rapid growth of LED industry, several premier analog IC suppliers have compiled a comprehensive LED driver guide for their products that would provide the designer with a vast choice of LED drivers based on their application needs. Four of the LED driver guide selections can be downloaded from the link below:

National Semiconductor :
http://www.national.com/appinfo/power/files/lighting_solutions.pdf

Linear Technology :
http://www.linear.com/ then select Power Management For LEDs

Arrow Electronics :
http://www.arrownac.com/industry_solutions/lighting/selector_guide.html

Supertex :
http://www.supertex.com/products/selector_guides

SUMMARY :

To ensure good long-term reliability and brightness uniformity, the LED shall be driven by constant current source. Since there are a wide range of LED drivers available in the market from different electronic IC manufacturers, the implementation of constant current drive becomes very simple without the need of extensive circuit design while minimizing the total component count.