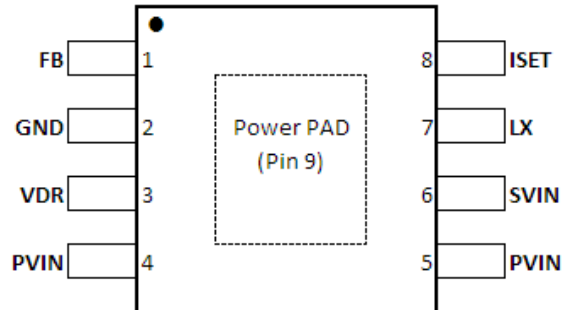


## 2A, 29V Non-Synchronous Buck Converter for LED Driver Applications

### FEATURES

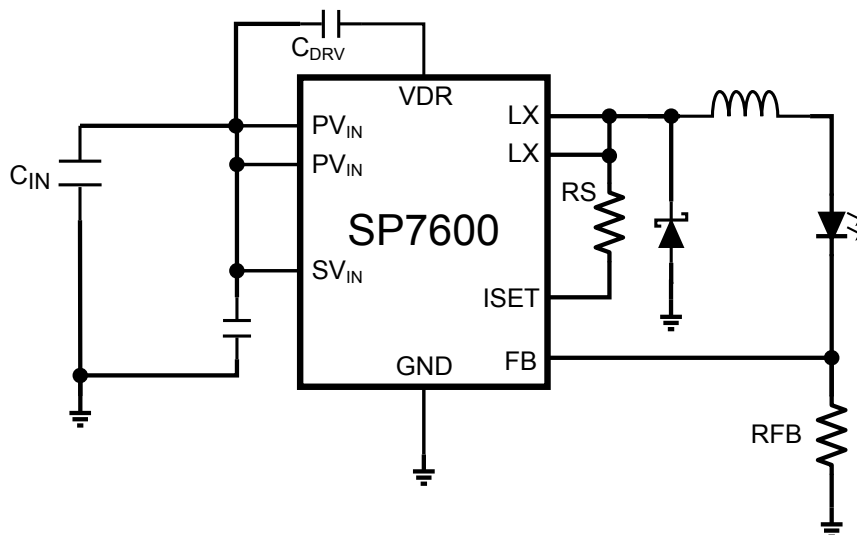
- Wide Input Voltage Range 4.5V – 29V
- 2 Amps Continuous Output Current
- Internal Compensation
- Input Feedforward Control improves Transient Response and Regulation
- 1200kHz Constant Frequency Operation
- Low 0.2V Reference Voltage
- Output setpoint accuracy of 2.5%
- PWM Dimming Capability
- HSOICN 8 pin Thermally Enhanced Package
- Lead Free, RoHS Compliant Package



### DESCRIPTION

The SP7600 is a PWM controlled step down (buck) voltage mode regulator with internal P-Channel MOSFET. It has a wide 4.5V to 30V single input voltage supply. The 200mV internal reference has been selected to allow ease of use in LED driver applications. It has a 5V LDO to power internal circuitry. Its built-in high-current PMOS driver and FET allow 100% duty ratio. The driver swings between  $V_{in}$  and  $V_{in}-5V$ , therefore another internal regulator with output of  $V_{in}-5V$  is used for powering the driver and over-current protection (OCP) circuitry. This 8-pin regulator with built in FET also has internal soft start, feed-forward PWM and internal Type-II loop compensation. The SP7600 is available in a space saving 8 pin HSOICN package.

### TYPICAL APPLICATION CIRCUIT





**ABSOLUTE MAXIMUM RATINGS**

These are stress ratings only and functional operation of the device at these ratings or any other above those indicated in the operation sections of the specifications below is not implied. Exposure to absolute maximum rating conditions for extended periods of time may affect reliability.

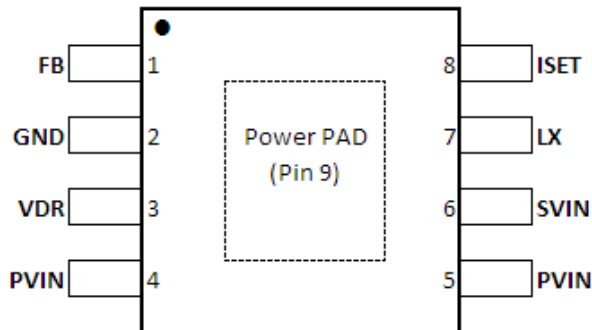
Input Voltage.....	-0.3V to 30V	Junction Temperature.....	-40°C to 125°C
Lx.....	-2V to 30V	Lead Temperature (Soldering, 10 sec).....	300 °C
FB.....	-0.3V to $V_{IN}+0.3V$	Thermal Resistance.....	59°C/W
Power Dissipation.....	Internally limited (Note 1)	ESD Rating (LX, ISET).....	1KV HBM
Storage Temperature.....	-65 °C to 150 °C	ESD Rating (all other pins).....	2KV HBM

**ELECTRICAL SPECIFICATIONS**

Specifications are for  $T_{AMB} = T_J = 25^\circ C$ , and those denoted by ♦ apply over the full operating range,  $-40^\circ C \leq T_J \leq 125^\circ C$ .

PARAMETER	MIN	TYP	MAX	UNITS	♦	CONDITIONS
UVLO Turn-On Threshold	4.0	4.2	4.5	V		$0^\circ C \leq T_J \leq 125^\circ C$
UVLO Turn-Off Threshold	3.8	4.0	4.3	V		$0^\circ C \leq T_J \leq 125^\circ C$
UVLO Hysteresis		0.2		V		
Operating Input Voltage Range	4.5		29	V		$0^\circ C \leq T_J \leq 125^\circ C$
Operating Input Voltage Range	7		29	V	♦	
Operating VCC Current		2	3	mA		VFB=0.1V, not switching
Standby VCC Current		0.6	1	mA		VFB=1.2V, not switching
Reference Voltage		200		mV		
Reference Voltage	186	200	214	mV	♦	
Switching Frequency	960	1200	1440	kHz		
Minimum ON-Pulse Duration		40	100	ns	♦	
Minimum Duty Cycle			0	%		
Maximum Duty Cycle	100			%		
VDR voltage	4.5		5.5	V	♦	Measure $V_{IN} - V_{DR}$ , $V_{IN} > 7V$
Overcurrent Threshold	300	350	400	mV		Measure $V_{IN} - LX$
ISET pin Input Current	25	33	40	uA	♦	$V_{LX} = V_{IN}$
OFF interval during hiccup		100		ms		
SHDN Threshold	0.8	1.0	1.2	V	♦	Apply voltage to FB
SHDN Threshold Hysteresis		100		mV		
Switch On Resistance		95		mΩ		
Switch Leakage		3	5	μA		

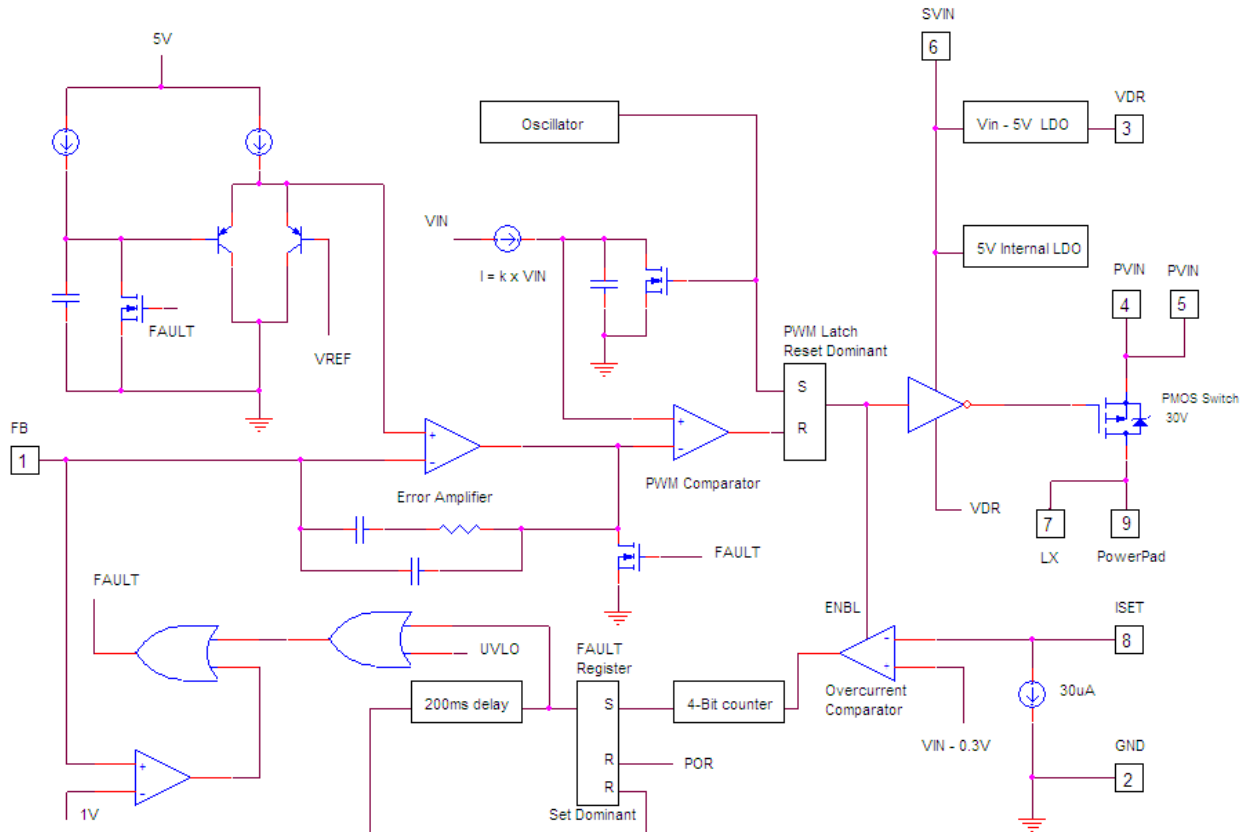
Note 1: All parameters tested at  $T_A = 25^\circ C$ . Specifications over temperature are guaranteed by design.



## PIN DESCRIPTION

PIN #	PIN NAME	DESCRIPTION
1	FB	Regulator feedback input. A current setting resistor is connected to LED's cathode and FB on one side and to ground on the other side. This pin can be also used for dimming control. By connecting a diode between this pin and a >2V signal the LED can be pulsed at up to 1kHz
2	GND	Ground pin.
3	VDR	Power supply for the internal driver. This voltage is internally regulated to about 5V below VIN. Place a 0.1uF decoupling capacitor between VDR and Vin as close as possible to the IC.
4,5	PVIN	Connection to the FET Source
6	SVIN	Input power supply for the regulator. Place input decoupling capacitor as close as possible to this pin. This is the Vin connection for the regulator and is not tied to the high-side FET.
7,9	LX	Connect to the output inductor. This is the P-Channel FET Drain
8	ISET	This pin is used as a current limit input for the internal current limit comparator. Connect to LX through an optional resistor. Internal threshold is pre-set to 350mV nominal and can be decreased by changing the external resistor based on the following formula: $V_{TRSHLD} = 350mV - 33uA * R$
9	Power Pad	Can be connected to inductor LX node for a thermal PAD – see Layout suggestions section.

## BLOCK DIAGRAM





## GENERAL OVERVIEW

The SP7600 is a fixed frequency, Voltage-mode, non-synchronous buck PWM regulator optimized for driving LEDs. Constant LED current is achieved using resistor RFB as shown in the page 1 schematic. A low 0.2V reference voltage minimizes power dissipation in RFB. A tight reference voltage tolerance of +/-3%, over full operating conditions, helps accurately program the LED current. High switching frequency of 1.2MHz (nominal) reduces the size of passive components. Dimming and power sequencing is achieved using a logic-level PWM signal applied to FB pin via a diode. Overcurrent protection (OCP) is based on high-side MOSFET's Rds(on) and is programmable via a resistor placed at LX node.

### Programming the LED current

Use the following equation to program the LED current:

$$R_{FB} = \frac{0.2V}{I_{LED}} \dots\dots\dots (1)$$

Where 0.2V is the SP7600 reference voltage

The output voltage will adjust as needed to ensure average  $I_{LED}$  is supplied. For example if the output current has to be set at 0.35A then  $R_{FB}=0.57$  Ohm. If the output LED has a corresponding  $V_f$  of 3.5V then SP7600 will step down the  $V_{in}$  to 3.5V. If two of these LEDs are placed in series then SP7600 will step down the voltage to 7V. Superimposed on  $I_{LED}$  there is a current ripple that is equal in magnitude to inductor current ripple. Current ripple will be nominally set to 10% of  $I_{LED}$  by proper sizing of inductor. Note that throughout this datasheet  $I_{LED}$  and  $I_o$  will be used interchangeably.

### Dimming Signal

A logic-level PWM signal applied through a small-signal diode to the feed-back (FB) pin can be used for dimming control of the LED. This external signal we call DIM turns the MOSFET gate drive on/off, thereby modulating the average current delivered to the LED. The DIM signal connects to the VFB pin through a 1N4148 diode and will shutdown the SP7600 when DIM = H and turn-on the SP7600 when DIM = L. The DIM signal needs to be greater than 600mV minimum to turn-off the SP7600 and less than 200mV to fully turn-on the SP7600. It is recommended to use a signal with DIM = 1V or more for OFF and 0V for ON. The user should note that the logic is reversed relative to many other PWM controlled LED drivers. In other words a logic level high at 20% duty cycle will result in approximately an 80% duty cycle for the LED. Recommended modulation frequencies are from 100Hz to 200Hz with 10 – 90% duty cycle, 500Hz with 10 – 80% duty cycle, and 1000Hz with 10 - 70% duty cycle. Figures 1 & 2 show the output response at the maximum PWM DIM signal of 1000Hz. See figure 3 for 100Hz to 1000Hz duty cycle response for two Luxeon K2 LEDs in parallel at 2A total current.

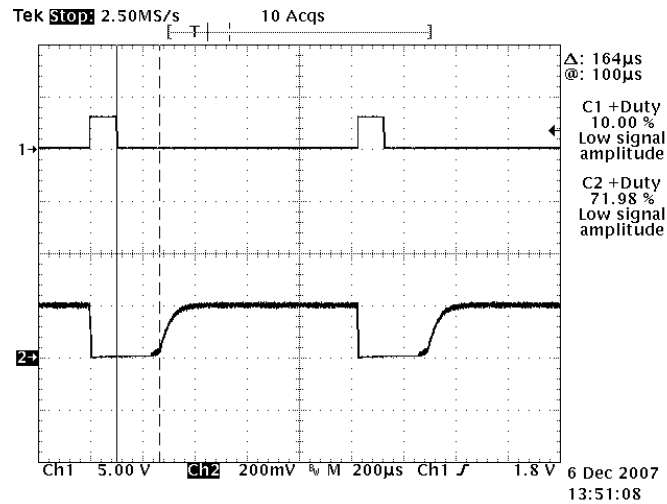


Figure 1. 1KHz, 10% duty cycle dimming signal is approximately 70% LED duty Cycle  
Ch1 = DIM signal, Ch2 = VFB 200mV/div = 2A Output current/div

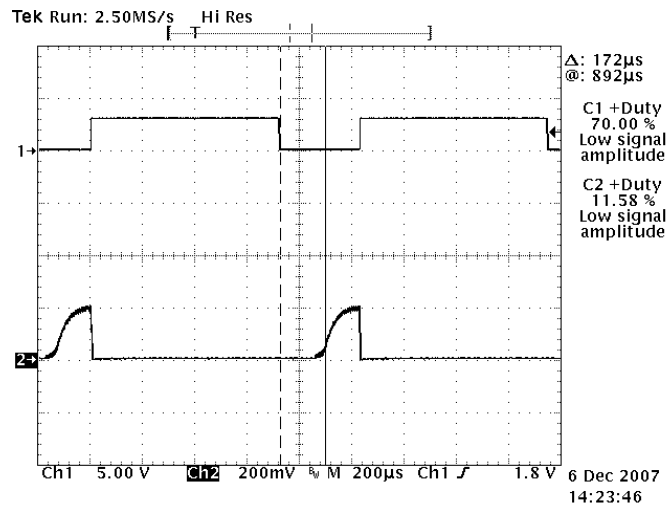


Figure 2. 1KHz, 70% duty cycle dimming signal is approximately 10% LED duty cycle  
Ch1 = DIM signal, Ch2 = VFB 200mV/div = 2A Output current/div

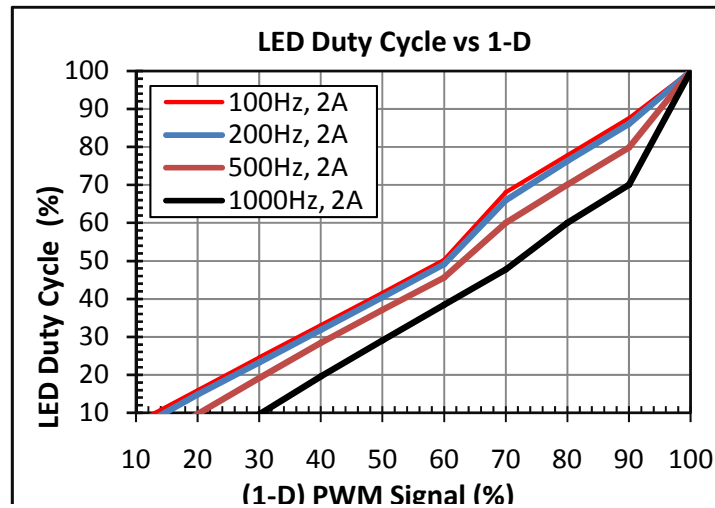


Figure 3. LED Duty Cycle Vs (1-D) DIM pin Duty Cycle with 12Vin, 2 Luxeon K2s in parallel at 2A total

### Modulator Operation and Power Sequencing

The SP7600 has a unique modulator design which improves the device's ability to operate at very high duty cycle. While seamless in operation as the duty cycle is increasing (input voltage falling), when the duty cycle is decreased (input voltage rising), the user will observe the switching frequency increasing in distinct fractions of the switching frequency. If the device is operating at 100% duty cycle, a unique advantage of using a p-channel pass device, and then the input voltage is increased, the frequency will start at 300kHz, then 600kHz, and then finally 1.2MHz. The frequency will tend to increase to the next higher fraction once the duty cycle reaches 75 to 65 percent. This is the normal operation of the device and should be expected. There is no impact on the LED current accuracy. If PWM dimming is being used as the input voltage is increased, one will see the frequency increasing when the duty cycle is < 90%. When power is initially applied the device will begin operating as if the input voltage is increasing and may start operation at one of the fractional operating frequencies. Many users will prefer to have the device start operating at the nominal operating frequency, thus it is recommended that Vin be applied after FB is set at the high state (>1.2V). The regulator is now in standby and once Vin has reached steady-state then FB is transitioned from a high to a low state. The regulator then starts operating at nominal frequency.

Another benefit of using power sequencing for power up is that it ensures all internal circuitry is alive and fully operational before the device is required to regulate the current through the LEDs. Since the regulator was "Off" before power was applied, it is unlikely the LED is under any type of thermal stress. EXAR does not recommend using the SP7600 in applications where dimming of the LED is achieved by PWM'ing the actual input power as is common in automotive dimming applications.

### Buck operation without output capacitor

In order to be able to apply the aforementioned dimming signal to the LED, the output filter capacitor that is normally used with a buck converter has to be removed from the circuit. Thus the LED current ripple equals the inductor current ripple. As a rule of thumb current ripple should be limited to 30% of I<sub>LED</sub>. Allowing for a higher current ripple, up to 30%, while staying within LED manufacturer ripple guidelines, will reduce inductance and possibly inductor size.



**Overcurrent Programming**

Resistor Rs can be used to program Overcurrent Protection (OCP). Use the following equation for calculating the Rs value.

$$R_s = \frac{0.35V - (1.5 \times 1.05 \times I_{ocp} \times R_{ds(on)})}{33\mu A} \dots\dots\dots (2)$$

Where Iocp is the programmed overcurrent and is generally set 50% above nominal output current, and Rds(on) = 95mohms.  
 Maximum value of Rs that can be used for programming OCP is 3k.

**Inductor Selection**

Select the inductor L1 for inductance, Irms and Isat. Calculate inductance from

$$L = \frac{V_o \times (V_{in} - V_o)}{V_{in} \times f \times \Delta I_L} \dots\dots\dots (3)$$

Where:

Vin is converter input voltage

Vo is converter output voltage. Since voltage across Rset is small, Vo approximately equals Vf (for a string of series connected LEDs Vo equals total Vf)

ΔIL is inductor current ripple (nominally set to 30% of Io)

Inductor Isat and Irms must allow sufficient safeguard over output current Io. As a rule of thumb these parameters should be 50% higher than Io. Where high efficiency is required a low DCR inductor should be used.

**Input capacitor selection**

Select the input capacitor for capacitance and ripple current rating. Use the capacitances listed in table 1 as a starting point and if needed increase Cin. Calculate the ripple current requirement from:

Io (A)	Cin (uF)
< 0.7	2.2
0.71 to 1.2	4.7
> 1.2	2 x 4.7

Table1- Cin selection

$$I_{rip} = I_o \times \sqrt{D(1 - D)} \dots\dots\dots (4)$$

Where D is converter duty cycle:

$$D = \frac{V_o}{V_{in}}$$

Ceramic capacitors are recommended for input filtering due to their low Equivalent Series Resistance (ESR), Equivalent Series inductance (ESL) and small form factor.



**Schottky Rectifier selection**

Select the Schottky D1 for Voltage rating  $V_R$  and current rating  $I_f$ . Recommended schottky diode voltage rating for 12V and 24V applications is 30V and 40V respectively. Current rating can be calculated from:

$$I_f \geq \sqrt{\left(1 - \frac{V_o}{V_{in}}\right)} \times I_o \dots\dots\dots (5)$$

Note that in applications where duty cycle is low, Schottky losses comprise a larger percentage of converter losses. In order to improve the efficiency in these applications choose a Schottky that meets the calculated current rating and has a lower  $V_f$ .

**Feedback resistor RFB**

R2 is part of SP7600 loop compensation network. Use a 30k R2 for  $V_{in}$  of 20V and larger. Use R2 of 60K for  $V_{in}$  less than 20V.

**Capacitor C5**

This is the decoupling capacitor for the power supply for the internal driver. Use a 0.1uF and place as closely to VDR and SVIN pins as possible.

**Design example** - Design a drive circuit for a 1.5A LED with a 12V input voltage. Nominal LED voltage is 3.6V.

1. Calculate RFB from equation (1):

$$RFB = \frac{0.2V}{1.5A} = 0.13\Omega$$

A standard value of 0.12ohm 0805 size is selected.

2. Calculate inductor value L1 from (3):

$$L1 = \frac{3.6V \times (12V - 3.6V)}{12V \times 1.3MHz \times 0.45A} = 4.3\mu H$$

An inductor of 4.7uH, rated at 3Arms and 3A Isat can be used.

3. Select input capacitor

A 10uF CIN (C1) is needed as shown in table 1. From (4) the ripple current rating of CIN is a fraction of 1.5A. A 10uF, 16V ceramic capacitor easily meets this requirement and offers low ESR and ESL.

4. Schottky current rating  $I_f$  can be calculated from (5):

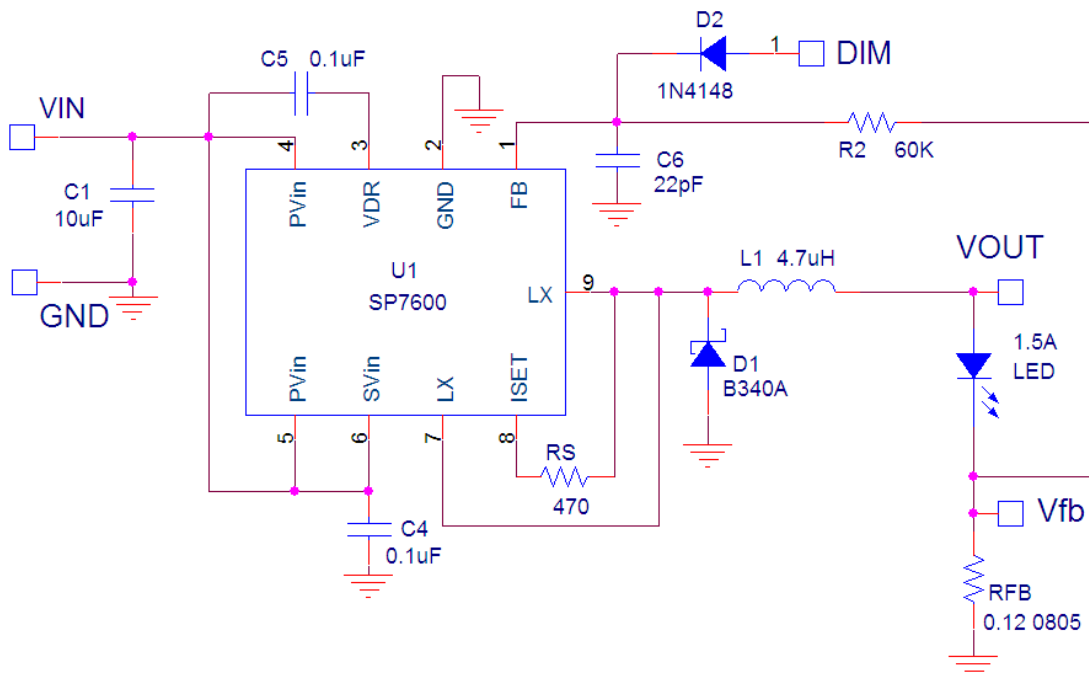
$$I_f \geq \sqrt{\left(1 - \frac{3.3V}{12V}\right)} \times 1.5A = 1.3A$$

Voltage rating should be 30V. B340A rated at 30V/3A or equivalent can be used for its ample current rating and low forward voltage.

5. Calculate  $R_s$  from (2):

$$R_s = \frac{0.35V - (1.5 \times 1.05 \times 2.25A \times 0.095\Omega)}{33\mu A} = 424\Omega$$

Use the standard resistor value for  $R_s$  of 470ohms.

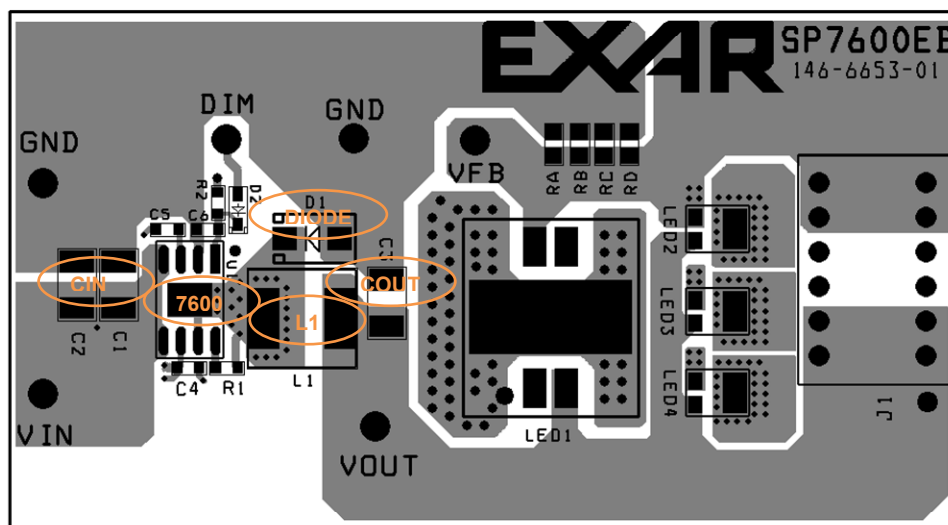


**Figure 4 - Circuit schematic for design example**

## Layout Suggestions

- i) Place the bypass capacitors C4 and C5 as close as possible to the 7600 IC. See figure 5 for details.
- ii) Create a pad under the IC that connects the power pad (pin 9) to the inductor. Duplicate this pad through the pcb layers if present, and on the bottom side of the PCB. Use multiple vias to connect these layers to aid in heat dissipation. Do not oversize this pad - since the LX node is subjected to very high dv/dt voltages, the stray capacitance formed between these islands and the surrounding circuitry will tend to couple switching noise
- iii) Connect the Schottky diode cathode as close as possible to the LX node and inductor input side. Connect the anode to a large diameter trace or a copper area that connects the input ground to the output ground.
- iv) The output capacitor, if used, should be placed close to the load. Use short wide copper regions to connect output capacitors to load to minimize inductance and resistances.
- v) Keep other sensitive circuits and traces away from the LX node in particular and away from the power supply completely if possible.

For more detail on the SP7600 layout see the SP7600EB Evaluation Board Manual available on our web site. Each layer is shown in detail as well as a complete bill of materials.



**Figure 5. SP7600 component side layout with critical power components labeled**



## Typical Performance Characteristics

The typical performance characteristics follow and begin with an illustration of the efficiencies that can be obtained with the SP7600 driving white LEDs in parallel for up to 3A total current or in series for 6 LEDs at up to 2A output current. For the 6 LED applications with a 24V input, the duty cycle is high and an efficiency of 94% can be obtained. For 12V input and 1 LED at 2A or 3A output, the duty cycle is much lower, but the efficiency is still over 80%. Note: to improve line regulation a small 22pF ceramic capacitor C6 should be placed from VFB to GND to filter out any noise obtained on the sensitive FB pin.

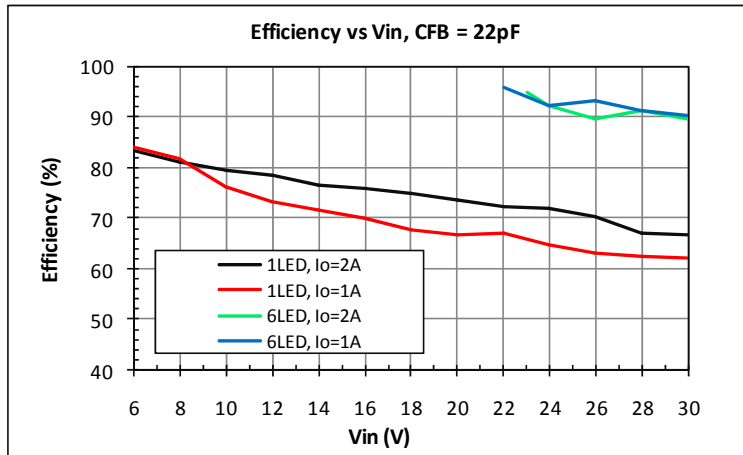
Scope photos of output ripple are shown for the typical application circuit for 6V input at 150mVpp ripple and at 29V input with over 400mVpp output ripple, both shown with no output capacitor. For comparison, an output ripple scope photo is shown with only 70mVpp when a 1uF capacitor is used at the output. For applications sensitive to output ripple, adding this relatively small 1206 sized 1uF 50V ceramic capacitor to the output provides a very good reduction in output ripple but since the value is only 1uF the circuit will still provide good PWM output response.

Vin startup scope photos are shown for 6V, 12V and 29V input with no problems in startup as shown in the Vout, VFB and especially the inductor current signal ILX.

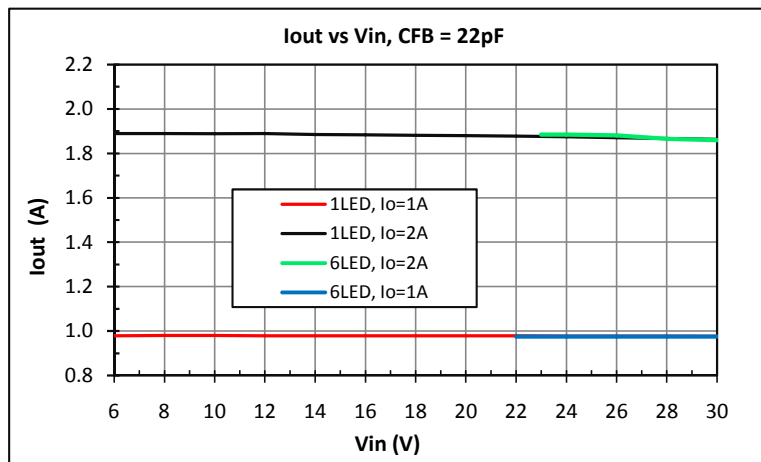
The last scope photos are for the output short circuit which causes a hiccup mode. The output can be shorted which causes a controlled automatic reset or hiccup mode of about 50 to 100msec period.

**TYPICAL PERFORMANCE CHARACTERISTICS**

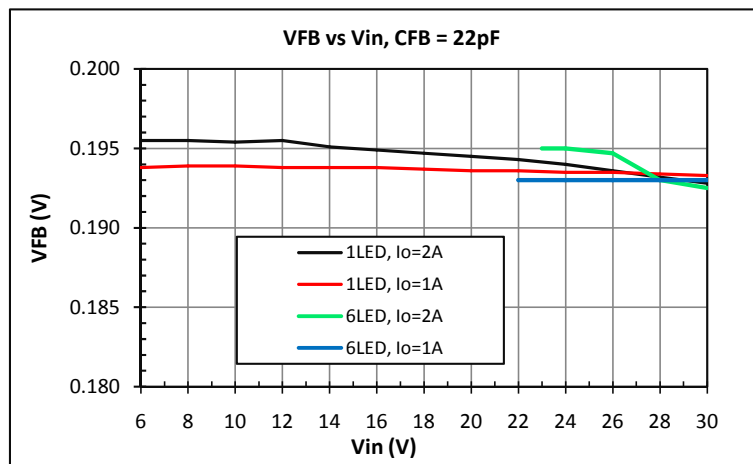
V<sub>IN</sub> = 12V, Figure 4 Application Circuit, T<sub>A</sub> = 25°C unless otherwise noted.



**Efficiency Vs Input Voltage**



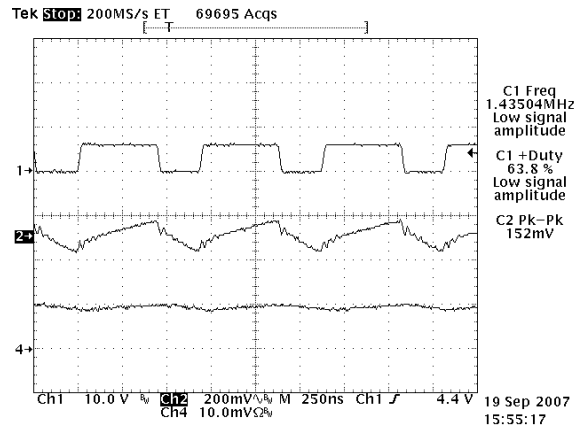
**Output Current Vs Input Voltage**



**Feedback Voltage Vs Input Voltage**

## TYPICAL PERFORMANCE CHARACTERISTICS

$V_{IN} = 12V$ , Figure 4 Application Circuit,  $T_A = 25^\circ C$  unless otherwise noted.

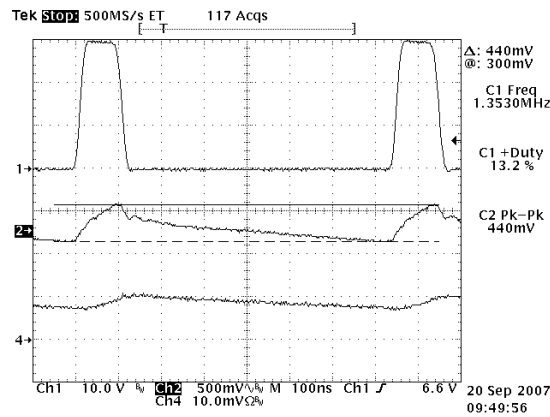


Ch1 = LX 10V/div

Ch2 = Vout(AC) 200mV/div

Ch4 = ILX 2A/div

**No Cout: Output Ripple = 150mVpp,  $V_{in} = 6V$ , 2LEDs in parallel,  $V_f = 3.6V$  at 2A**

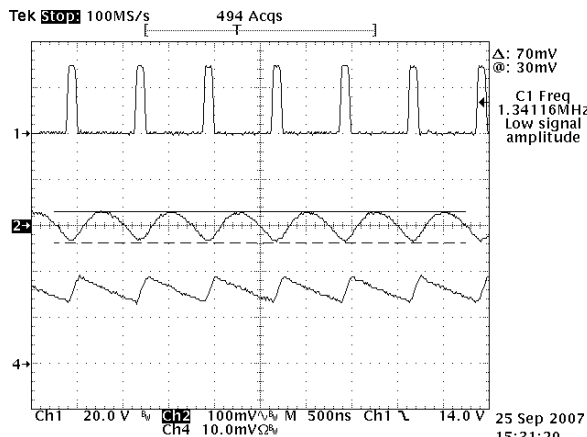


Ch1 = LX 10V/div

Ch2 = Vout(AC) 500mV/div

Ch4 = ILX 2A/div

**No Cout: Output Ripple = 440mVpp,  $V_{in} = 29V$ , 2LEDs in parallel,  $V_f = 3.6V$  at 2A**



Ch1 = LX 20V/div

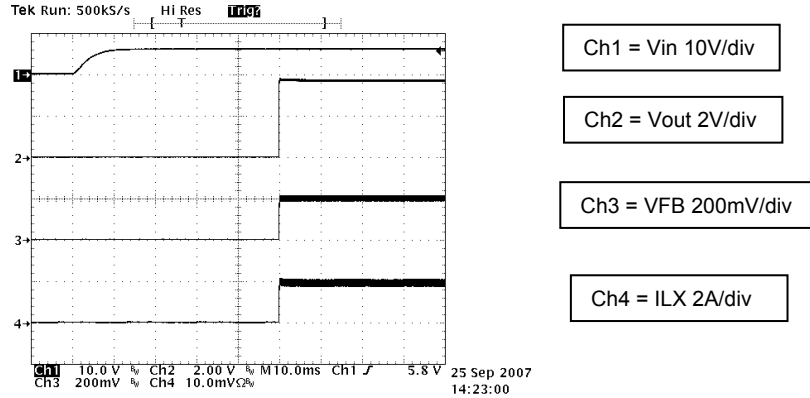
Ch2 = Vout(AC) 100mV/div

Ch4 = ILX 2A/div

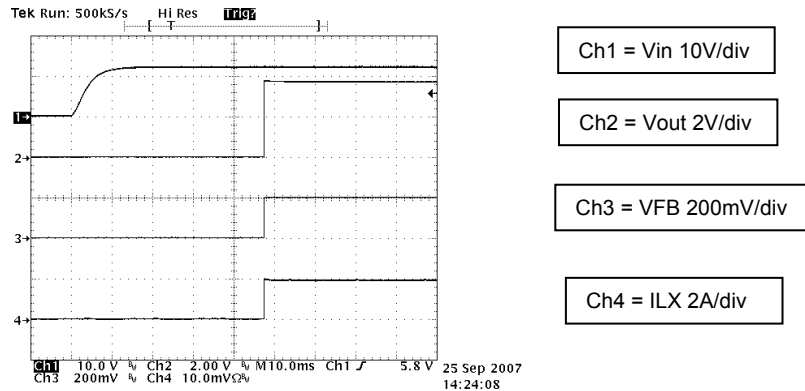
**Cout = 1uF: Output Ripple = 70mVpp,  $V_{in} = 29V$ , 2LEDs in parallel,  $V_f = 3.6V$  at 2A**

## TYPICAL PERFORMANCE CHARACTERISTICS

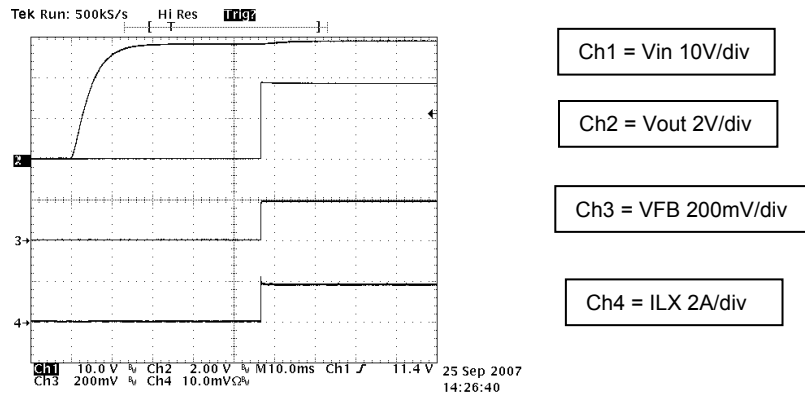
V<sub>IN</sub> = 12V, Figure 4 Application Circuit, T<sub>A</sub> = 25°C unless otherwise noted.



**6V VIN Startup: 2LEDs in parallel, V<sub>f</sub> = 3.6V at 2A**



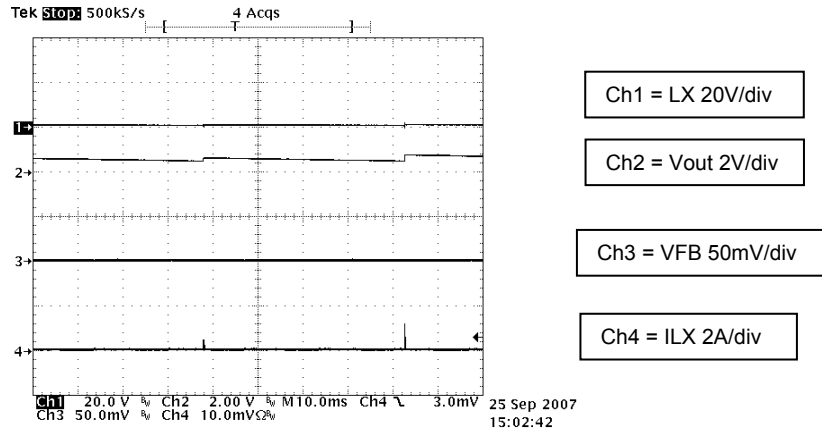
**12V VIN Startup: 2LEDs in parallel, V<sub>f</sub> = 3.6V at 2A**



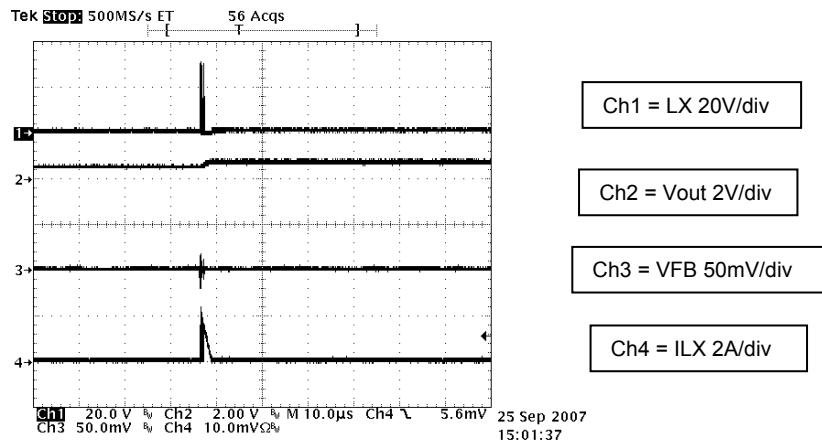
**29V VIN Startup: 2LEDs in parallel, V<sub>f</sub> = 3.6V at 2A**

**TYPICAL PERFORMANCE CHARACTERISTICS**

V<sub>IN</sub> = 12V, Figure 4 Application Circuit, T<sub>A</sub> = 25°C unless otherwise noted.



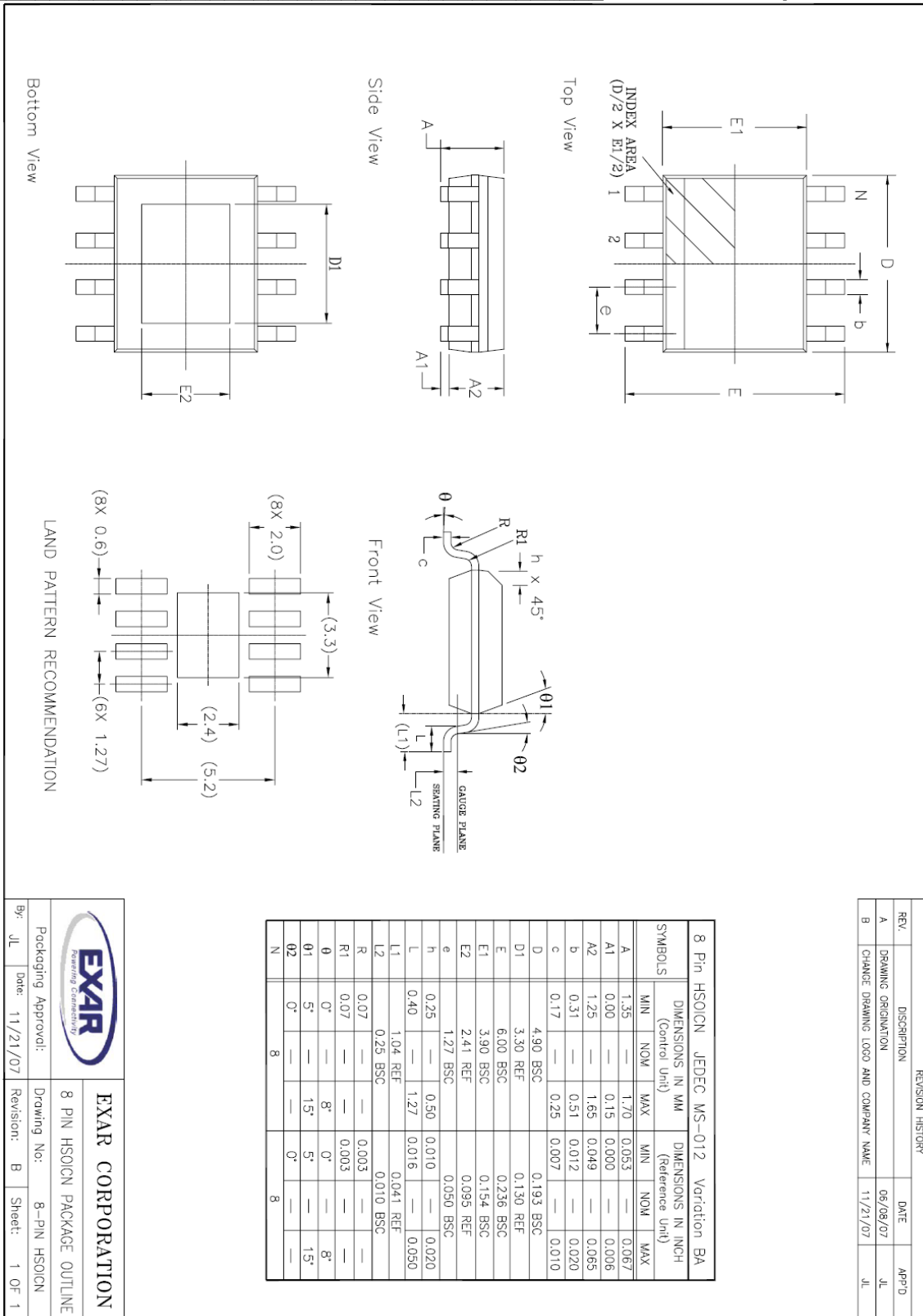
**Output Short-circuit: Hiccup mode with V<sub>IN</sub> = 29V**



**Output Short-circuit: Zoomed in on Hiccup mode with V<sub>IN</sub> = 29V**



PACKAGE: 8-pin HSOICN



REVISION HISTORY			
REV.	DESCRIPTION	DATE	APP'D
A	DRAWING ORIGINATOR	06/08/07	JL
B	CHANGE DRAWING LOGO AND COMPANY NAME	11/21/07	JL

8 Pin HSOICN		JEDEC MS-012		Variation BA		
SYMBOLS	DIMENSIONS IN MM (Control Unit)			DIMENSIONS IN INCH (Reference Unit)		
	MIN	NOM	MAX	MIN	NOM	MAX
A	1.35	—	1.70	0.053	—	0.067
A1	0.00	—	0.15	0.000	—	0.006
A2	1.25	—	1.65	0.049	—	0.065
b	0.31	—	0.51	0.012	—	0.020
c	0.17	—	0.25	0.007	—	0.010
D	4.90	BSC	—	0.193	BSC	—
D1	3.30	REF	—	0.130	REF	—
E	6.00	BSC	—	0.236	BSC	—
E1	3.90	BSC	—	0.154	BSC	—
E2	2.41	REF	—	0.095	REF	—
e	1.27	BSC	—	0.050	BSC	—
h	0.25	—	0.50	0.010	—	0.020
L	0.40	—	1.27	0.016	—	0.050
L1	1.04	REF	—	0.041	REF	—
L2	0.25	BSC	—	0.010	BSC	—
R	0.07	—	—	0.003	—	—
R1	0.07	—	—	0.003	—	—
θ	0°	—	8°	0°	—	8°
θ1	5°	—	15°	5°	—	15°
θ2	0°	—	—	0°	—	—
N	8	—	—	8	—	—

		<b>EXAR CORPORATION</b>	
		8 PIN HSOICN PACKAGE OUTLINE	
By: JL	Date: 11/21/07	Drawing No: 8-PIN HSOICN	Revision: B
Packaging Approval:		Sheet: 1 OF 1	



**ORDERING INFORMATION**

Model	Junction Temperature Range	Package Type
SP7600EN2-L.....	-40°C to +125°C .....	(Lead-free) 8-pin HSOICN
SP7600EN2-L/TR.....	-40°C to +125°C .....	(Lead-free) 8-pin HSOICN

/TR = Tape & Reel

**REVISION HISTORY**

DATE	REVISION	DESCRIPTION
December 2007	A	Original Release

For further assistance:

Email: [customersupport@exar.com](mailto:customersupport@exar.com)  
EXAR Technical Documentation: <http://www.exar.com/TechDoc/default.aspx?>



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