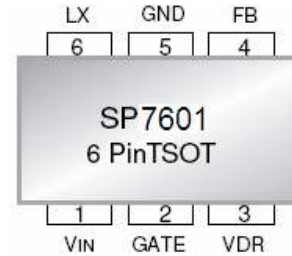


## 29V High Voltage LED Driver

### FEATURES

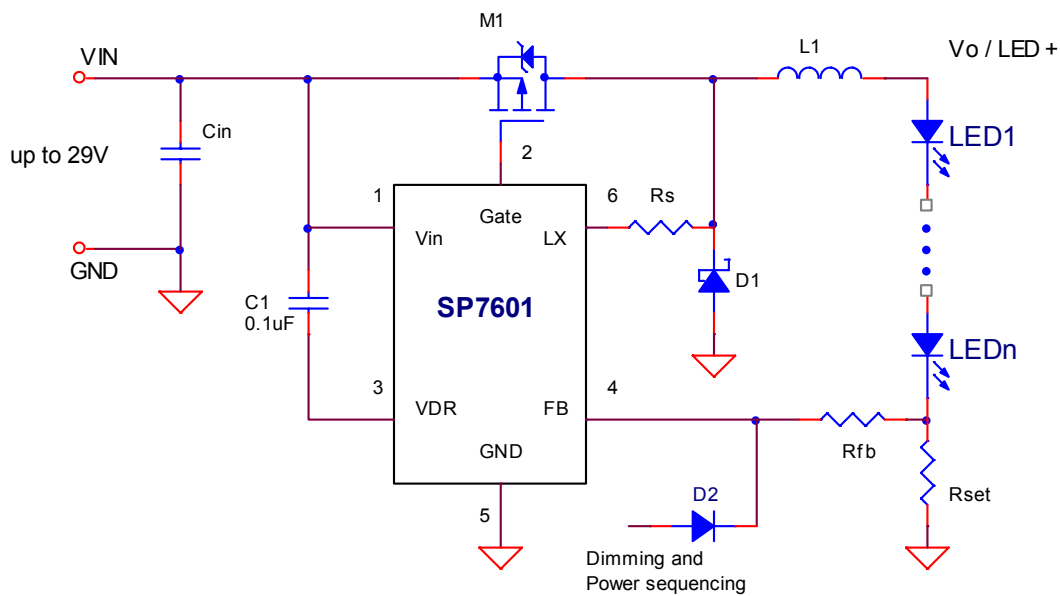
- Wide Input Voltage Range 4.5V – 29V
- 1.2MHz Constant Frequency Operation
- Low 0.2V Reference Voltage
- Adjustable Overcurrent Protection
- PWM Dimming and Power sequencing Control
- RoHS Compliant, Lead Free Packaging:  
Small 6-Pin TSOT Package



### DESCRIPTION

The SP7601 is a high current DC to DC Switching Buck LED Driver that features low component count and high efficiency due to a very low 0.2V reference voltage. High 1.2MHz switching frequency allows use of very small external components. The SP7601 is compatible with PWM dimming up to a frequency of 1kHz at 10% Duty Cycle.

### 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
Lx.....	-2V to 30V
FB.....	-0.3V to 5.5V
Storage Temperature.....	-65 °C to 150 °C
Junction Temperature.....	-40°C to 125°C
Lead Temperature (Soldering, 10 sec).....	300 °C
ESD Rating.....	1kV LX, 2kV all other nodes, HBM

## ELECTRICAL SPECIFICATIONS

Specifications are for  $T_{AMB}=T_J=25^{\circ}C$ , and those denoted by  $\blacklozenge$  apply over the full operating range,  $-40^{\circ}C < T_J < 125^{\circ}C$ . Unless otherwise specified:  $V_{IN} = 4.5V$  to  $29V$ ,  $C_{IN} = 4.7\mu F$ .

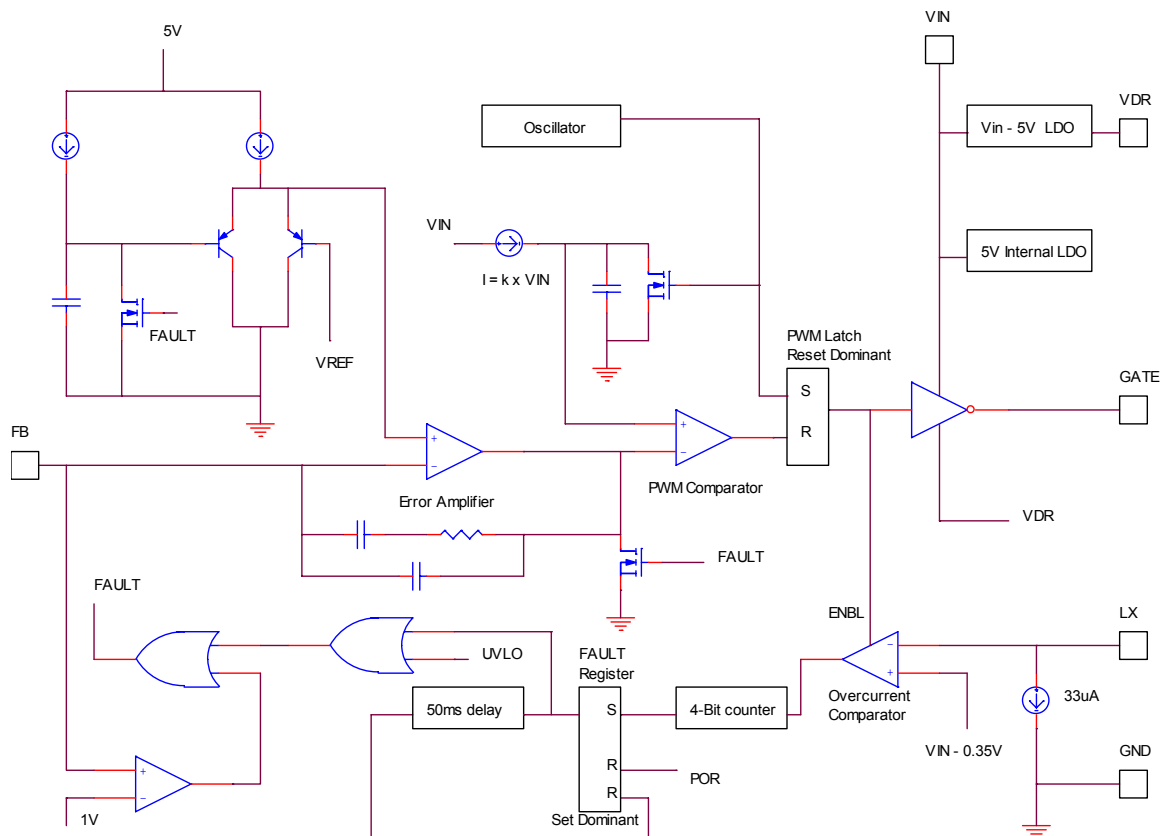
PARAMETER	MIN	TYP	MAX	UNITS	$\blacklozenge$	CONDITIONS
UVLO Turn-On Threshold	4.0	4.2	4.5	V		0°C to 125°C
UVLO Turn-Off Threshold	3.8	4.0	4.3	V		0°C to 125°C
UVLO Hysteresis		0.2		V		
Operating Input Voltage Range	4.5		29	V		0°C to 125°C
Operating Input Voltage Range	7		29	V	$\blacklozenge$	
Operating VCC Current		2	3	mA		VFB=0.1V, gate not switching
Standby VCC Current		0.6	1	mA		VFB=1.2V, gate not switching
Reference Voltage		0.2		V		
Reference Voltage	0.186		0.214	V	$\blacklozenge$	
Switching Frequency	960	1200	1440	kHz		
Peak-to-peak ramp Voltage		$V_{in}/10$		V		Ramp clamped to $\leq 4.2V$
Minimum ON-Pulse Duration		40	100	ns	$\blacklozenge$	
Minimum Duty Cycle			0	%		
Maximum Duty Cycle	100			%		
Gate Driver Turn-Off Resistance		50	60	k $\Omega$		Internal resistor between GATE and VIN
Gate Driver Pull-Down Resistance		4	8	$\Omega$		$V_{IN}=12V$ , $V_{FB}=0.1V$ , Measure resistance between GATE and VDR
Gate Driver Pull-up Resistance		3	6	$\Omega$		$V_{IN}=12V$ , $V_{FB}=0.3V$ , Measure resistance between GATE and VIN
VIN - VDR voltage difference	4.5		5.5	V	$\blacklozenge$	Measure VIN – VDR, VIN>7V
Overcurrent Threshold	300	350	400	mV		Measure VIN - LX
LX pin Input Current	25	33	40	$\mu A$		$V_{LX} = V_{IN}$
OFF interval during hiccup		50		ms		
SHDN Threshold	0.8	1.0	1.2	V	$\blacklozenge$	Apply voltage to FB
SHDN Threshold Hysteresis		100		mV		



## PIN DESCRIPTION

PIN #	PIN NAME	DESCRIPTION
1	VIN	Input power supply for the controller. Place the input decoupling capacitor as close as possible to this pin.
2	GATE	Connect to the gate terminal of the external P-channel MOSFET.
3	VDR	Power supply for the internal driver. This voltage is internally regulated to about 5V below VIN. Place the decoupling capacitor between VDR and VIN as close as possible to the IC.
4	FB	Regulator feedback input. A feedback resistor is connected between this pin and the LED cathode. A current setting resistor is connected between the cathode and ground of the LED. This pin can be also used for dimming control and/or Power Sequencing.
5	GND	Ground pin.
6	LX	This pin is used as a current limit input for the internal current limit comparator. Connect to the drain pin of the external MOSFET 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: $V_{TRSHLD} = 350\text{mV} - 33\mu\text{A} * R$

## BLOCK DIAGRAM



The SP7601 is a fixed frequency, Voltage-mode, non-synchronous buck PWM controller optimized for driving LEDs. Constant LED current is achieved using resistor  $R_{SET}$  as shown in the page 1 schematic. A low 0.2V reference voltage minimizes power dissipation in  $R_{SET}$ . A tight reference voltage tolerance of  $\pm 7\%$ , 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 the FB pin via a diode. Overcurrent protection (OCP) is based on the high-side MOSFET's  $R_{DS(ON)}$  and is programmable via a resistor placed at the LX node.

**Programming the LED Current**

Use the following equation to program the LED current:

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

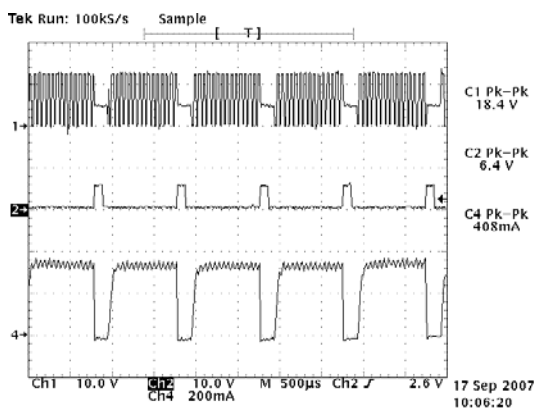
Where 0.2 is SP7601 reference voltage

The output voltage will adjust as needed to ensure average  $I_{LED}$  is supplied. For example, if

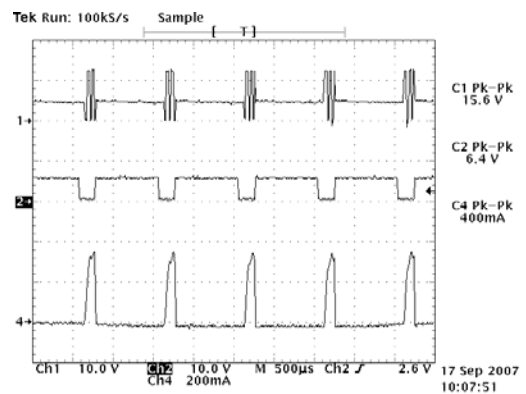
the output current is to be set at 0.35A, then  $R_{SET} = 0.57\Omega$ . If the output LED has a corresponding  $V_f$  of 3.5V, then the SP7601 will step down the  $V_{IN}$  to 3.5V. If two of these LEDs are placed in series, then SP7601 will step down the voltage to 7V. Superimposed on  $I_{LED}$  current is a current ripple that is equal in magnitude to the inductor current ripple. Current ripple will be nominally set to 10% of  $I_{LED}$  by proper sizing of the inductor. Note that throughout this datasheet  $I_{LED}$  and  $I_{OUT}$  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 to control dimming of the LED. This signal turns the MOSFET gate drive on/off, thereby modulating the average current delivered to the LED. For turning the MOSFET off, the minimum signal amplitude at the FB node must be 1.2V; and to turn it back on it must fall below 0.7V. The frequency of the PWM signal can be up to 1kHz.



**Figure1- 1kHz, 10% duty cycle dimming signal applied to SP7601, ch1:LX, ch2: dimming signal, ch4:  $I_{LED}$**



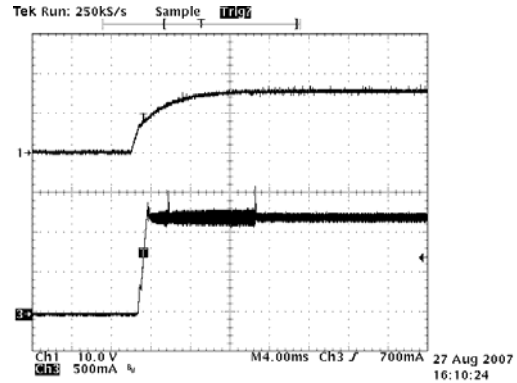
**Figure2- 1kHz, 80% duty cycle dimming signal applied to SP7601, ch1:LX, ch2: dimming signal, ch4:  $I_{LED}$**

### Modulator Operation and Power Sequencing

The SP7601 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 400kHz, 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  $V_{IN}$  be applied after FB is set at the high state (>1.2V). The regulator is now in standby and once  $V_{IN}$  has reached steady-state, then FB is transitioned from a high to a low state. The controller 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. Depending on the operating conditions, there may be short duration (<100 $\mu$ s) current spikes during initial application of  $V_{IN}$ . Figure 3 shows an example of the current spikes.



**Figure 3- current spikes generated at startup when power sequencing is not used, ch1:VIN, ch2: Iout**

LEDs are capable of handling these short duration spikes as long as they are not operating at their thermal limit. 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 SP7601 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 must 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 10% of  $I_{LED}$ . Allowing for a higher current ripple, while staying within LED manufacturer ripple guidelines, will reduce inductance and possibly inductor size.



**Overcurrent Programming**

Resistor  $R_s$  can be used to program Overcurrent Protection (OCP). Use equation 2 for calculating the  $R_s$  value:

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

Where  $I_{ocp}$  is the programmed overcurrent and is generally set 50% above nominal output current. The maximum value of  $R_s$  that can be used for programming OCP is 3kΩ.

**Inductor Selection**

Select the inductor L1 for inductance,  $I_{RMS}$  and  $I_{SAT}$ . Calculate inductance from

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

Where:

- $V_{in}$  is converter input voltage
- $V_o$  is converter output voltage. Since voltage across  $R_{SET}$  is small,  $V_o$  approximately equals  $V_F$  (for a string of series connected LEDs  $V_o$  equals total  $V_F$ )
- $\Delta I_L$  is inductor current ripple (nominally set to 10% of  $I_o$ )

Inductor  $I_{SAT}$  and  $I_{RMS}$  must allow sufficient safeguard over output current  $I_o$ . As a rule of thumb these parameters should be 50% higher than  $I_o$ . 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  $C_{IN}$ .

$I_o$ (A)	$C_{in}$ (uF)
< 0.7	2.2
0.71 to 1.2	4.7
> 1.2	2 x 4.7

**Table1-  $C_{IN}$  selection**

Calculate the ripple current requirement from:

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

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.

**MOSFET selection**

Select the MOSFET M1 for ON resistance  $R_{DS(ON)}$ , voltage rating ( $B_{VDSS}$ ) and gate-to-drain charge ( $Q_{GD}$ ). The recommended MOSFET voltage rating for 12V and 24V applications is 30V and 40V respectively. As a rule of thumb  $Q_{GD}$  should be less than 10nC.  $R_{DS(ON)}$  must be selected such that, when operating at peak current and junction temperature, the Overcurrent threshold of the SP7601 is not exceeded. Allowing 50% margin for temperature coefficient of  $R_{DS(ON)}$ , 5% margin for inductor current ripple and 50% margin for OCP, the following expression can be used:

$$R_{ds(ON)} \leq \left( \frac{350mV}{1.5 \times 1.5 \times 1.05 \times I_o} \right) \dots (5)$$

Within this constraint, selecting MOSFETs with lower  $R_{DS(ON)}$  will reduce conduction losses at the expense of increased switching losses. If a choice of several MOSFETs is available, select the highest  $R_{DS(ON)}$  MOSFET that meets the above criteria.

**Schottky Rectifier selection**

Select the Schottky D1 for Voltage rating  $V_R$  and current rating  $I_f$ . Voltage rating should be selected using the same guidelines outlined for MOSFET voltage selection. Current rating can be calculated from:

$$I_f \geq \sqrt{\left(1 - \frac{V_o}{V_{in}}\right)} \times I_o \dots (6)$$

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**

RFB is part of the SP7601 loop compensation network. Use a 30kΩ RFB for  $V_{IN}$  of 20V and larger. Use RFB of 60KΩ for  $V_{IN}$  less than 20V.

**Capacitor C1**

This is the decoupling capacitor for the power supply to the internal driver. Use a 0.1μF capacitor and place it as closely to the VDR and  $V_{IN}$  pins as possible.

**Design example-** Design a drive circuit for a 0.35A LED with a 12V input voltage. Nominal LED voltage is 3.3V.

1. Calculate RSET from equation (1):

$$R_{set} = \frac{0.2V}{0.35A} = 0.57\Omega$$

2. Calculate inductor value L1 from (3):

$$L1 = \frac{3.3V \times (12V - 3.3V)}{12V \times 1.2MHz \times 0.035A} = 57\mu H$$

A COILTRONICS LD-560 inductor rated at 56μH, 0.5ARMS and 0.57ASAT can be used.

3. Select input capacitor:

A 2.2μF  $C_{IN}$  is needed as shown in table 1. From equation (4), the ripple current rating of  $C_{IN}$  is a fraction of 0.35A. A 2.2μF, 16V ceramic capacitor easily meets this requirement and offers low ESR and ESL.

4.  $R_{DS(ON)}$  is calculated from equation (5):

$$R_{DS(ON)} \leq \left( \frac{350mV}{1.5 \times 1.5 \times 1.05 \times 0.35A} \right) = 0.42\Omega$$

$B_{VDS}$  should be at least 30V and  $Q_{GD}$  should be less than 10nC. An ANPEC APM4427K with  $R_{DS(ON)}=0.14 \Omega$ ,  $B_{VDS}=30V$  and  $Q_{GD}=1.1nC$  can be used.

5. Schottky current rating  $I_F$  can be calculated from (6):

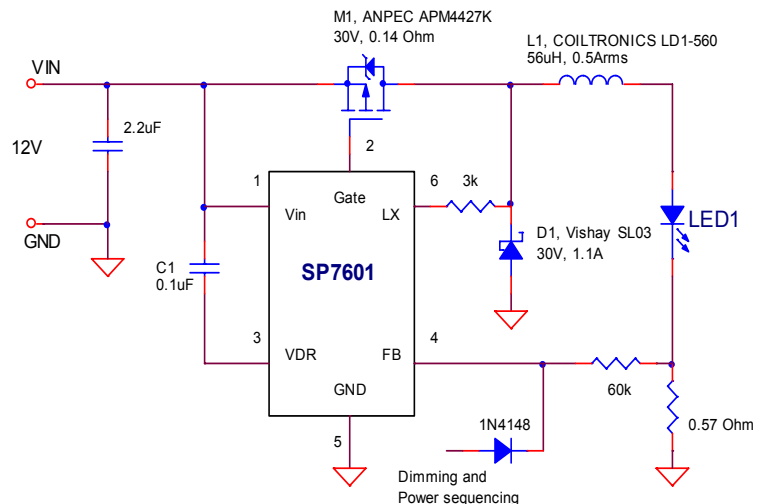
$$I_f \geq \sqrt{\left(1 - \frac{3.3V}{12V}\right)} \times 0.35 A = 0.3 A$$

Voltage rating should be 30V. An SL03 rated at 30V/1.1A or equivalent can be used.

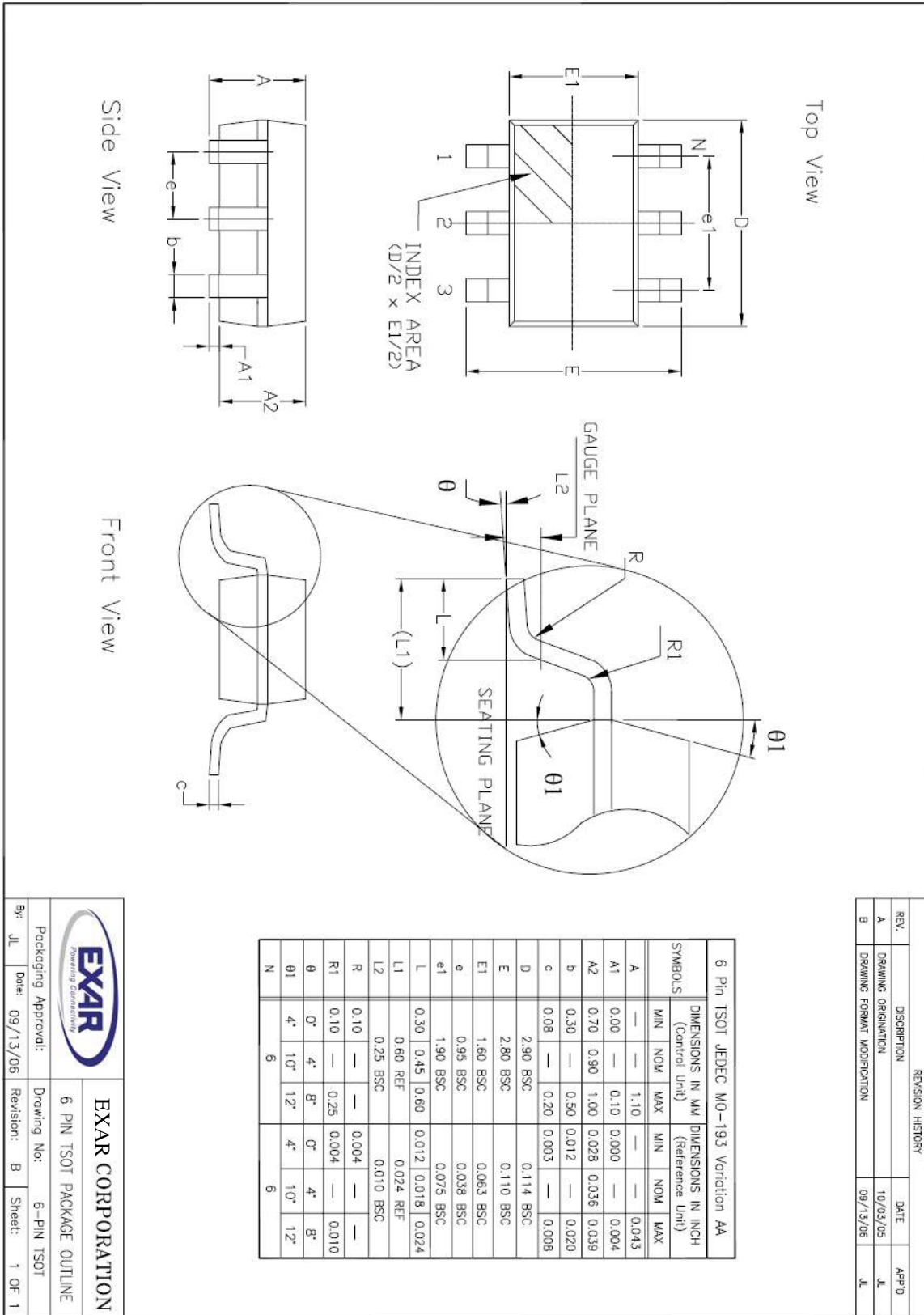
6. Calculate  $R_s$  from equation (2):

$$R_s = \frac{0.35V - (1.5 \times 1.05 \times 0.525A \times 0.14\Omega)}{33\mu A} = 7098\Omega$$

Use the maximum recommended  $R_s$  of 3kΩ since the calculated value is larger.



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



REVISION HISTORY			
REV.	DISCRIPTION	DATE	APP'D
A	DRAWING ORIGINATOR	10/03/05	JL
B	DRAWING FORMAT MODIFICATION	09/13/06	JL

6 Pin TSOT JEDEC MO-193 Variation AA							
SYMBOLS	DIMENSIONS IN MM (Control Unit)			DIMENSIONS IN INCH (Reference Unit)			
	MIN	NOM	MAX	MIN	NOM	MAX	
A	—	1.10	—	—	—	0.043	
A1	0.00	0.10	0.000	—	—	0.004	
A2	0.70	0.90	1.00	0.028	0.036	0.039	
b	0.30	—	0.50	0.012	—	0.020	
c	0.08	—	0.20	0.003	—	0.008	
D	2.90 BSC			0.114 BSC			
E	2.80 BSC			0.110 BSC			
E1	1.60 BSC			0.063 BSC			
e	0.95 BSC			0.038 BSC			
e1	1.90 BSC			0.075 BSC			
L	0.30	0.45	0.60	0.012	0.018	0.024	
L1	0.60 REF			0.024 REF			
L2	0.25 BSC			0.010 BSC			
R	0.10			0.004			
R1	0.10			0.004			0.010
θ	0°			4°			8°
θ1	4°			10°			12°
N	6			6			

**EXAR CORPORATION**

6 PIN TSOT PACKAGE OUTLINE

Packaging Approval: JL Date: 09/13/06

Drawing No: 6-PIN TSOT

Revision: B Sheet: 1 OF 1





## ORDERING INFORMATION

Part Number	Min Temp °C	Max Temp °C	RoHS/Lead Free	Theta JA °C/W	MSL Level	Pack Type	Quantity	Package
SP7601EK1-L	-40	125	Yes	134	L1 @ 260°C	Canister	Any	6 Pin TSOT
SP7601EK1-L/TR	-40	125	Yes	134	L1 @ 260°C	Tape & Reel	2500	6 Pin TSOT
SP7601_EB	-40	125	Not Applicable to Evaluation Board					Board

For further assistance:

Email: [Sipexsupport@sipex.com](mailto:Sipexsupport@sipex.com)  
WWW Support page: <http://www.sipex.com/content.aspx?p=support>  
Application Notes: <http://www.sipex.com/applicationNotes.aspx>

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