

Constant current controller for high brightness LEDs

Introduction

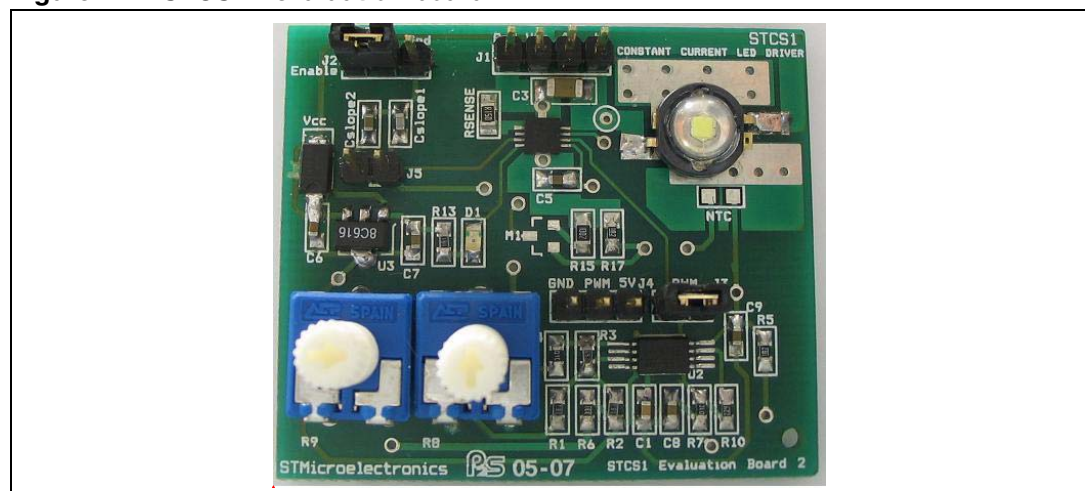
The recent improvements in high power light-emitting diode (LED) technology with 100 lumens per LED chip and efficiency higher than that of incandescent lamps bring solid state lighting close to reality. Light-emitting diodes (LEDs) have become very popular in the area of general lighting as a replacement technology for low voltage lighting. Customers are recognizing the advantages of using LED lighting which include long operating life, no fragile glass, and low voltage DC operated.

LEDs are now available in higher and higher wattages per package (1 W, 3 W and 5 W) with currents up to 1.5 A. At these current levels, the traditional means of limiting current with a resistor are not sufficiently accurate nor efficient. It is well known that the brightness of LEDs is proportional to the forward current. The best way to supply LEDs is to control the forward current in order to get a good match of the output light. LED manufacturers specify the characteristics (such as lumens, beam pattern, color) of their devices at a specified forward current (IF) but they do not specify these characteristics at a specific forward voltage (VF). In order to better control the LED current under several application conditions, STMicroelectronics has developed the STCS1, a device which not only guarantees a constant LED current but also provides useful features that make the device suitable for different applications such as advertising signs, automotive interior and exterior lighting, and emergency vehicle warning lights. This document describes how to use the STCS1 evaluation board. It includes a schematic diagram, bill of materials (BOM), and test data.

Table 1. Device summary

Description	Order code
STCS1A evaluation board	STCS1ADEMO1

Figure 1. STCS1A evaluation board



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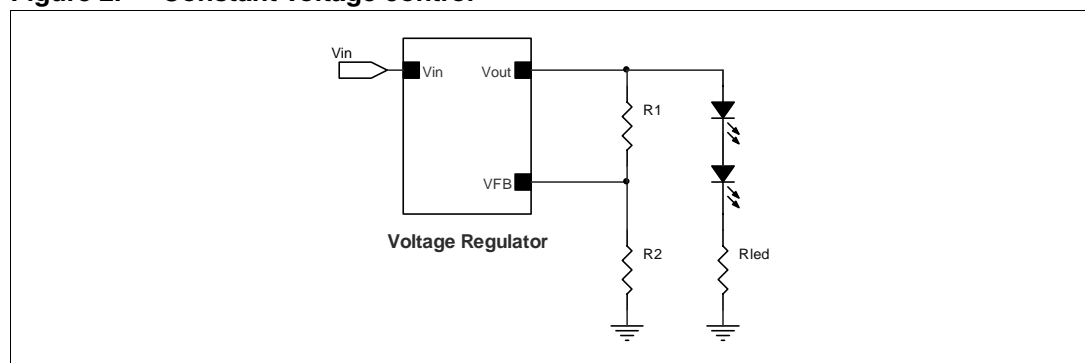
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1 Background

In designing a power supply for white high brightness LEDs, the main requirements are efficiency, size, and cost of the complete solution.

LEDs are current-driven devices whose brightness is proportional to their forward current. Forward current can be controlled in two ways: voltage mode and current mode. The first method uses the LED V-I curve to determine what voltage has to be applied to the LED in order to generate the desired forward current. This is typically accomplished by applying a voltage source and using a ballast resistor as shown in [Figure 2](#). The output voltage required for the circuit in [Figure 1](#) is given in [Equation 1](#). This method does not provide adequate current control or the system efficiency necessary for high current LEDs.

Figure 2. Constant voltage control

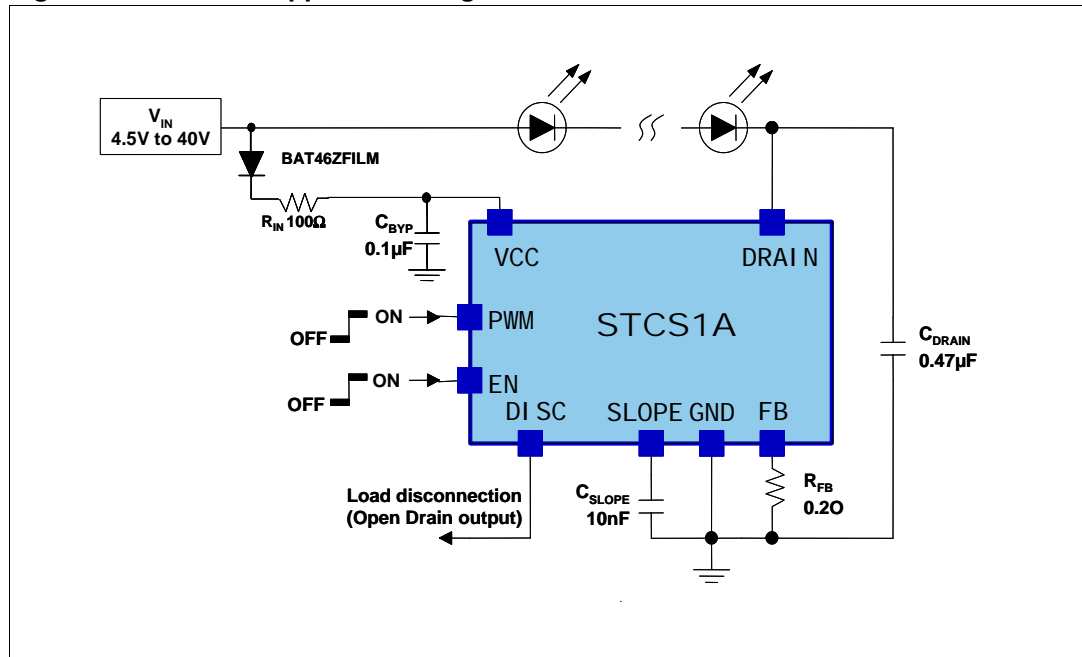


Equation 1

$$V_{OUT} = V_{FB} \left(1 + \frac{R_1}{R_2} \right) = n \cdot V_{EMAX} + I_{LED} \cdot R_{LED}$$

Controlling current accurately is a challenge when each LED has a large manufacturing tolerance in its forward voltage. The best way to drive the LEDs is to control the forward current in order to eliminate the brightness variations due to forward voltage spread of the LEDs. [Figure 3](#) shows the STCS1 application diagram. In this case the controller regulates the voltage across a current-sense resistor rather than regulating the output voltage.

Figure 3. STCS1A application diagram for 0.5 A LED current



2 Detailed description

The STCS1 is designed to supply high power LEDs under the severe conditions of automotive and industrial applications resulting in constant brightness and extended LED lifetime.

The STCS1 is a BiCMOS constant current controller designed to provide a precise constant current starting from a variable input voltage source. STCS1 is well suited for applications requiring high voltage input and it is able to withstand automotive load-dump events up to 40 V. An external shunt resistor in the ground path of the connected LEDs is used to sense the LED current. A regulation loop holds the voltage drop at the shunt resistor on a constant level of 100 mV (typ.). The potential difference across the sense resistor is compared to a fixed reference voltage and the error is both amplified and used to drive the internal power series pass device. Selecting the sense resistance permits adjusting the output current level up to 1.5 A with a precision of $\pm 10\%$. The integrated PWM input of the STCS1 allows LED brightness regulation by pulse width modulation. The luminosity spread arising from the LED production process can be compensated via software by an appropriate duty cycle applied to the PWM pin. The STCS1A version has a specific pin which allows the user to set of the slope of the edges of the LED current during the PWM dimming mode.

The device assembled on the demonstration board is the STCS1A, so the user will be able to test this feature. It is possible to disable this feature by removing the C_{SLOPE} capacitors. An open drain pin output provides information on load disconnection.

A more detailed description of STCS1 device can be found in the STCS1 datasheet.

3 Pin functions

Table 2. Pin function

Pin. No.	Symbol	Function
1	VCC	Supply voltage. Must be closely decoupled to ground.
2	PWM	PWM dimming input. With PWM high the internal power MOSFET is turned on and the LEDs current goes to the set value. With PWM low the power MOSFET is turned off and the LEDs current goes to zero. While the PWM input is switching, the overall circuitry remains on. This is necessary and needed in order to implement two important features: short delay time and controlled slope for the current.
3	EN	Shutdown pin. With EN high the STCS1 is in ON mode. When the EN pin is low the device is completely off and the current consumption is less than 1 μ A.
4	DRAIN	Internal power N-MOSFET drain.
5	FB	Internal power N-MOSFET source. This pin is the voltage pin feedback. The control loop regulates the voltage in this pin to 100 mV. The LEDs current is set with an external sensing resistor connected between this pin and GND.
6	GND	Ground pin.
7	SLOPE	STCS1A capacitor for slope control. This pin permits setting the slope of the rise and fall edge of LEDs current. The rise and fall slope of the current is controlled by the C_{SLOPE} capacitor. The slope control is achieved charging/discharging C_{SLOPE} with a constant current. If this pin is not connected the slope control feature is disable and the STCS1A part has the same behavior of STCS1.
8	DISC	Open drain logic output. If V_{DRAIN} is lower than 75 mV, the DISC pin is pulled low regardless of the PWM pin status. This information can be used by the system to alert that a problem occurs in the LEDs.
	Exposed pad	Connect to the ground plane for effective power dissipation. The exposed pad is internally connected to ground.

4 Description of the board

The evaluation board module (EVM) is configured as constant current supply. An external power source ranging from 4.5 V to 40 V must be connected to the V_{CC} and GND pins of J1 connector.

For proper operation, the minimum input voltage must always be:

Equation 2

$$V_{INMIN} = n \cdot V_{EMAX} + V_{DROPOutMAX}$$

where $n \cdot V_{EMAX}$ is the total forward voltage of all series connected LEDs and $V_{DROPOutMAX}$ is the maximum voltage between drain and GND with a current on I_{LEDs} equal to 1.5 A.

The current regulation is accomplished by regulating the voltage across a current sense resistor. The EVM does not operate correctly unless a load is placed between (J1-A) and (J1-K). No-load condition is indicated by the turn-on of the LED D1. The EVM allows the user to place one Lumileds LED LXHLPW09 directly soldered on the board. A different or a higher number of LEDs may be used externally, by connecting the LED anode to J1-A and the LED cathode to J1-K.

The evaluation board embeds an internal oscillator able to implement a PWM dimming technique. The board gives the user the possibility to change both the frequency and the duty cycle of the PWM signal using the corresponding R8 and R9 trimmer. The user is able to change the average current on the LEDs branch by modifying the duty cycle of the PWM signal between 0% to 100% using the R9 trimmer.

It is possible to send an external PWM signal to the PWM pin. This operation is accomplished by providing the PWM signal between the PWM and GND pins of the J4 connector and keeping the J3 connector floating.

4.1 Input/output connections

[Table 3](#) describes the input/output connections.

Table 3. Input/output connections

Reference designator	Name	Description
J1	Vin/LEDs	<p>V_{CC} and GND pins.</p> <ul style="list-style-type: none"> – Positive and negative connections to the input power supply [4.5 V, 40 V]. <p>If LED is mounted on the evaluation board:</p> <ul style="list-style-type: none"> – V_{CC} and A pins shorted. <p>If external LEDs are used:</p> <ul style="list-style-type: none"> – Connecting the LEDs chain between A and K pins. – V_{CC} and A pins shorted to supply LEDs branch.
J2	Enable	<p>Use this connector to enable and disable the controller.</p> <ul style="list-style-type: none"> – EN and the 5 V pins shorted to enable the controller. – EN and the GND pins shorted to disable the controller. – If EN pin is left open, the EVM does not operate correctly.

Table 3. Input/output connections (continued)

Reference designator	Name	Description
J3/J4	PWM	<p>Continuous current mode:</p> <ul style="list-style-type: none"> – J3: Floating – J4: PWM and 5 V pins shorted. <p>PWM dimming mode with oscillator implemented on board. In this configuration the PWM pin of STCS1 receives the PWM signal generated by the oscillator on the board.</p> <ul style="list-style-type: none"> – J3: Shorted – J4: Floating. <p>PWM dimming mode with external PWM signal:</p> <ul style="list-style-type: none"> – J3: Floating. – J4: External PWM signal between PWM and GND pins.
J5	Slope capacitor	<ul style="list-style-type: none"> – Floating: $C_{SLOPE} = 1 \text{ nF}$ and $T_{RISE/FALL} = 0.1 \text{ msec}$ – Shorted: $C_{SLOPE} = 100 \text{ nF}$ and $T_{RISE/FALL} = 10 \text{ msec}$

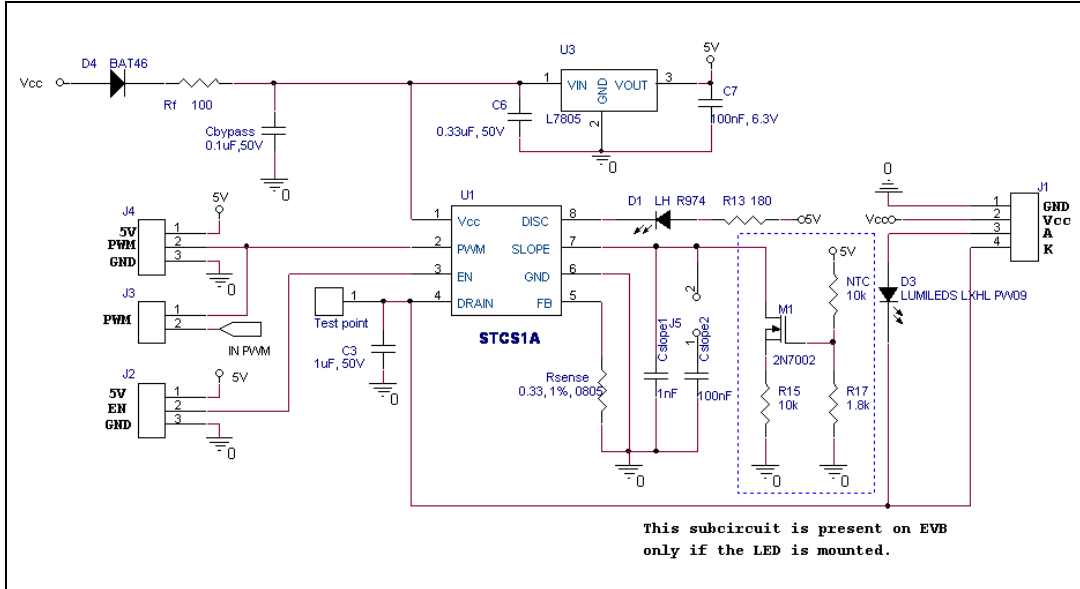
4.2 Setup

1. Connect a power supply source between the V_{CC} and GND pin of J1. The EVM operates between 4.5 V and 40 V. Ensure that the input voltage never exceeds the STCS1 absolute maximum input voltage rating of 45 V.
2. Connect the LEDs between the LED anode (J1 - A) and LED cathode (J1 - K) connection points.
3. Connect V_{CC} and A pins of J1 connector with a jumper to supply the LEDs branch.
4. Enable jumper:
 - a) En = GND shutdown
 - b) En = 5 V ON mode
5. Continuous current mode: PWM = 5 V
 - a) Jumper between PWM and 5 V pins of J4 connector
 - b) No jumper on J3 connector
6. Dimming mode with the PWM signal of the oscillator implemented on evaluation board.
 - a) No jumper on J4 connector
 - b) Jumper on J3 connector
 - c) R8: by changing the value of this resistor, the dimming frequency varies from 20 Hz up to 1.7 kHz
 - d) R9: It is possible to change the duty cycle of the PWM signal from zero to 100%.
7. Dimming mode with external PWM signal.
 - a) No jumper on J3.
 - b) External PWM signal between PWM-J4 and GND-J4 pins

5 Schematic and bill of materials

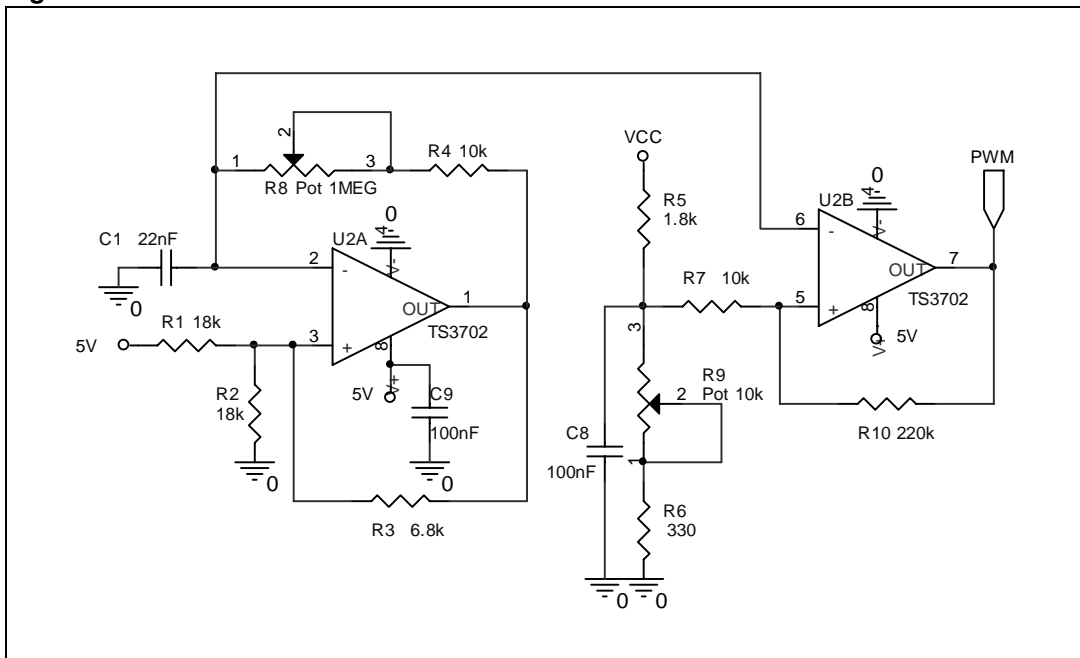
5.1 Schematic

Figure 4. Schematic - power section



This subcircuit is present on the evaluation board only if the LED is mounted (see the highlighted blue box in [Figure 4](#)).

Figure 5. Schematic - PWM oscillator



5.2 Bill of materials (BOM)

Table 4. Bill of materials

Qty	Ref.	Description	Part number	Manufacturer	Footprint
1	C1	22 nF ± 10%, X7R, 16 V	GRM188R71C223KA01	Murata	0603
1	C _{SLOPE1}	1 nF ± 10%, X7R, 16 V	GRM155R71C102KA01	Murata	0805
1	C3	1 μF ± 10%, X7R, 50 V	GRM21BR71H105KA12	Murata	0805
4	C _{SLOPE2} , C7,C8,C9	100 nF ± 10%, X7R, 16 V	GRM219R71C104KA01	Murata	0805
1	C _{bypass}	0.1 μF ± 10%, X7R, 50 V	GRM21BR71H104KA01	Murata	0805
1	C6	0.33 μF ± 10%, X7R, 16 V	GRM21BR71C334KA01	Murata	0805
1	D1	Disc LED	LH R974		
1	D3	White LED	LXHLPW09 B	Lumileds	
1	D4	Schottky diode	BAT46ZFILM	STMicroelectronics	SOD-123
1	J1	CON4			
2	J2,J4	CON3			
1	J3	CON2			
1	J5	JUMPER			
3	R4,R7	10 kΩ 1%, 1/16 W			0805
1	Rf	100 Ω 1%, 1/16 W			0805
1	R _{sense}	0.33 Ω ± 1%, 1/4 W			0805
2	R2,R1	18 kΩ ± 1%, 1/4 W			0805
1	R3	6.8 kΩ ± 1%, 1/4 W			0805
2	R5	1.8 kΩ ± 1%, 1/4 W			0805
1	R6	330 ± 1%, 1/4 W			0805
1	R8	Pot 1MEG			-
1	R9	Pot 10 k			-
1	R10	220 kΩ ± 1%, 1/4 W			0805
1	R13	180 ± 1%, 1/4 W			0805
1	U1	Current control	STCS1APUR	STMicroelectronics	QFN 3X3-8L
1	U2	Comparator	TS3702IPT	STMicroelectronics	SOG.65M/8/ WG8.20/L3.17
1	U3	Voltage regulator	L78L05ABUTR	STMicroelectronics	SOT89

6 Board layout

The following main guidelines should be followed for the board layout:

- The sense resistor must be placed as close as possible to feedback and ground pins. The traces should be as short as possible.
- STCS1 exposed pad area should be as large as possible to improve power dissipation. If a 2-layer PCB is used, one layer should be assigned as ground layer and a good connectivity between both layers should be observed.

Figure 6, Figure 7 and Figure 8 show the board layout for the STCS1 constant current control evaluation board.

Figure 6. Assembly layer

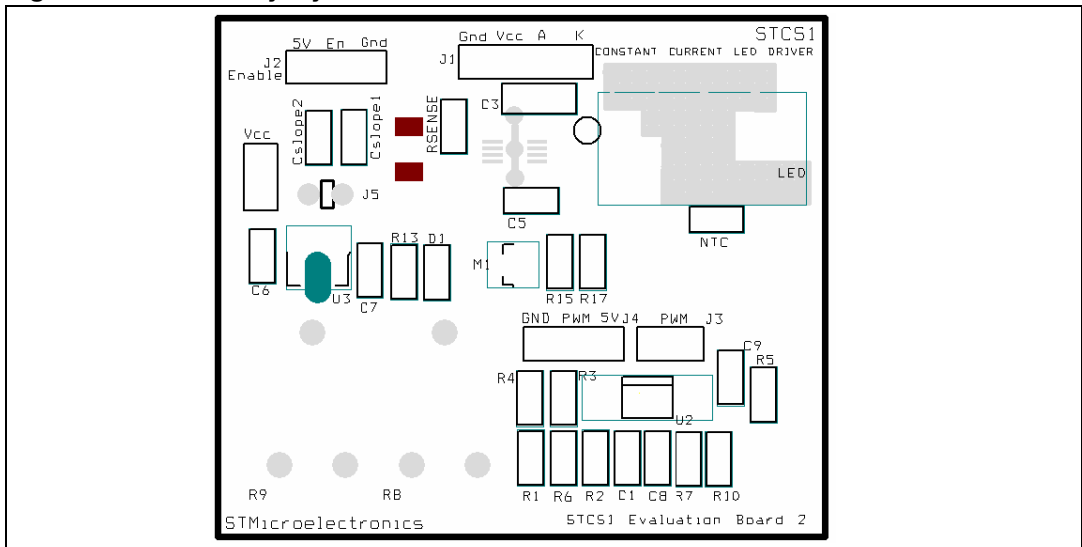


Figure 7. Top layer

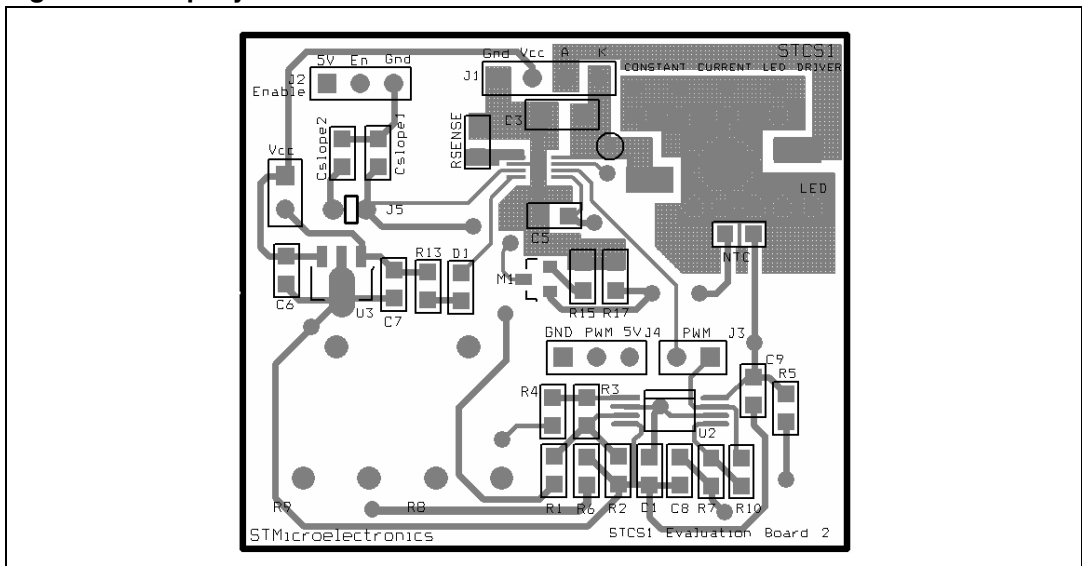
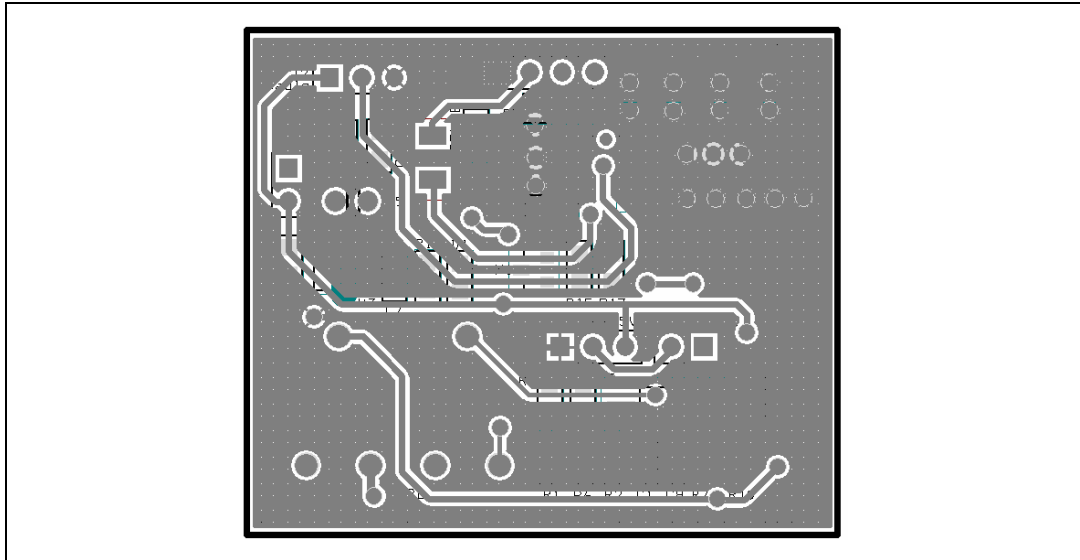


Figure 8. Bottom layer



7 Application information

7.1 Thermal information

The STCS1 is able to control an LED current up to 1.5 A and it is able to sustain a voltage between drain pin and GND up to 40 V. Those operating conditions are however limited by thermal constraints. Typical thermal resistances are shown in [Table 5](#). In particular R_{thJA} depends on the copper area and the number of layers of the printed circuit board under the pad. DFN8 and PowerSO-8 have an exposed die attach pad which enhances the thermal conductivity enabling high power application.

Table 5. Thermal data

Symbol	Parameter	MLP 3x3 8L	PowerSO-8	Unit
R_{thj-C}	Thermal resistance junction-case	3	10	°C/W
$R_{thj-amb}$	Thermal resistance junction-ambient	37.6 ⁽¹⁾	45 ⁽²⁾	

1. This value is referred to four-layer PCB, JEDEC standard test board.
2. With two sides, two planes PCB following EIA/JEDEC JESD51-7 standard.

The power dissipation in the device can be calculated as:

Equation 3

$$P_D = (V_{DRAIN} - V_{FB}) \cdot I_{LED} + (V_{CC} \cdot I_{CC})$$

Based on this and on the thermal resistance and ambient temperature, the junction temperature can be calculated as:

Equation 4

$$T_J = R_{thJA} \cdot P_D + T_A$$

For correct operation of the chip, the junction temperature must not exceed 110 °C. The following graphs show the maximum power dissipation according to the ambient temperature for both packages:

Figure 9. Maximum power dissipation vs T_A for MLP 3x3

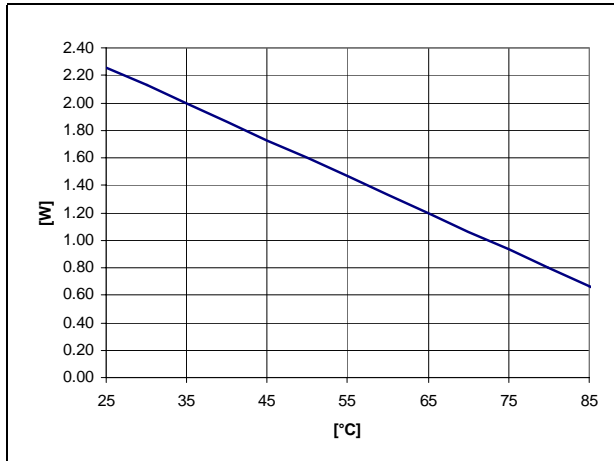
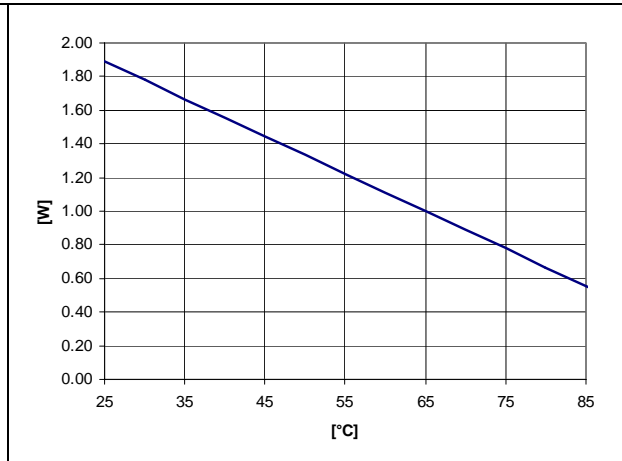


Figure 10. Maximum power dissipation vs T_A for PowerSO-8



8 Revision history

Table 6. Document revision history

Date	Revision	Changes
23-May-2007	1	Initial release
25-Feb-2008	2	<ul style="list-style-type: none"> – Modified: Figure 3, 4, Table 2 and Section 2 – Nota in Table 3 removed

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