A BATTERY CHARGER USING TSM101

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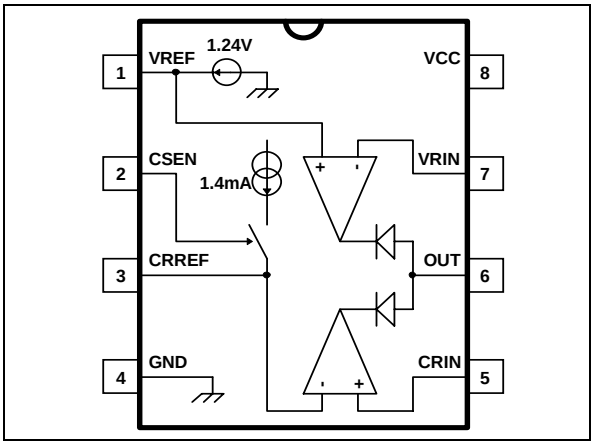
This technical note shows how to use the TSM101 integrated circuit with a switching mode power supply (SMPS) to realize a battery charger.
An example of realization of a 12V Nickel-Cadmium battery charger is given.

1 - TSM101 PRESENTATION

The TSM101 integrated circuit incorporates a high stability series band gap voltage reference, two ORed operational amplifiers and a current source (Figure 1).

Figure 1 : TSM101 Schematic Diagram



This IC compares the DC voltage and the current level at the output of a switching power supply to an internal reference. It provides a feedback through an optocoupler to the PWM controller IC in the primary side.
The controlled current generator can be used to modify the level of current limitation by offsetting the information coming from the current sensing resistor.
A great majority of low or medium end power supplies is voltage regulated by using shunt programmable voltage references like the TL431 (Figure 2).
The galvanic insulation of the control information is done by using an optocoupler in linear mode with a variable photo current depending on the difference between the actual output voltage and the desired one.
A current limitation is used to protect the power supply against short circuits, but lacks precision. This limitation is generally realized by sensing the current of the power transistor, in the primary side of the SMPS.
The role of the TSM101 is to make a fine regulation of the output current of the SMPS and a precise voltage limitation.
The primary current limitation is conserved and acts as a security for a fail-safe operation if a short-circuit occurs at the output of the charger.

2 - PRINCIPLE OF OPERATION

The current regulation loop and the voltage limitation loop use an internal 1.24V band-gap voltage reference. This voltage reference has a good precision (better than 1.5%) and exhibits a very stable temperature behavior.
The current limitation is performed by sensing the voltage across the low ohmic value resistor R_5 and comparing it to a fixed value set by the bridge composed by R_2 and R_3 (Figure 3).
When the voltage on R_5 is higher than the voltage on R_3 the output of the current loop operational amplifier decreases. The optocoupler current increases and tends to reduce the output voltage by the way of the PWM controller.
The voltage regulation is done by comparing a part of the output voltage (resistor bridge R_6, R_7 and P_1) to the voltage reference (1.24V).
If this part is higher than 1.24V, the output of the voltage loop operational amplifier decreases.
The optocoupler current increases and tends to reduce the output voltage by the way of the PWM controller.
By enabling the TSM101 current source (pin 2) it is possible to offset the current sensing by a voltage equal to :

$$V_{OFF} = R_4 \cdot I_0$$

with I_0 = 1.4mA
This offset lowers the output charge current and this function can be used to charge two types of batteries having different capacities. The current source is enabled by connecting pin 2 to ground.

3 - CALCULATION OF THE ELEMENTS

The charge current is regulated at 700mA (if the charge control input is left open) or 200mA (if the charge control input is put to ground), allowing the charge of two different types of batteries.

3.1 Voltage limitation

The end-of-charge voltage is limited at 1.45V/cell, this is the recommended voltage for an ambient temperature at 25°C.

A diode is generally inserted at the output of the charger to avoid the discharge of the battery if the charger is not powered. This diode is sometimes directly integrated in the battery pack. The influence of this diode on the charge is negligible if the voltage drop (0.7V) is taken into account during the design of the charger.

The voltage at the output of the charger is :

$$V_{OUT} = \frac{R_6 + R_7}{R_6} \cdot V_{ref}$$

and regarding R_6 and R_7 :

$$R_6 = \frac{V_{ref}}{V_{out} + V_{ref}} \cdot R_7$$

(P_1 which is a part of R_6 and R_7 is not considered in this equation)

The following values are used on the application board :

- R_7 = 12kΩ
- R_6 = 1kΩ
- P_1 = 220Ω adjust for V_{output} = 15.2V with the battery replaced by a 1kΩ resistor
- R_{10} = short circuit
- C_3 = 100nF

3.2 Current regulation

R_5 is the sense resistor used for current measurement.

The current regulation is effective when the voltage drop across R_5 is equal to the voltage on pin 5 of the TSM101 (assuming that the internal current source is disabled).

For medium currents (<1A), a voltage drop across R_5 of 200mV = V_{R5} is a good value, R_5 can be realized with standard low cost 0.5W resistors in parallel.

$$R_5 = \frac{V_{R_5}}{I_{ch}} = 0.285\Omega$$

(four 1.2Ω resistor in parallel)

R_2 and R_3 can be chosen using the following formula :

$$R_6 = R_3 \cdot \frac{V_{ref} - V_{R_5}}{V_{R_5}}$$

3.3 Charge control

If the pin 2 is left open, the charge current is nominal at 700mA.

If pin 2 is connected to ground, the internal current source is enabled, the current measurement is offset by a voltage equal to :

$$V_{R_4} = I_0 \cdot R_4$$

with I_0 = 1.4mA

This can be used to lower the charging current or eventually to stop the charge, if $V_{R4} > V_{R5}$.

In our example, the current offset is equal to 700 - 200mA = 500mA, representing a voltage offset V_{R4} = 140mV across R_4.

The following values are used on the application board :

- R_5 = 300mΩ (four 1.2Ω-0.5W resistors in parallel)
- R_4 = 100Ω
- R_2 = 1.2kΩ
- R_3 = 220Ω
- R_9 = short circuit
- R_1 = 10kΩ
- C_2 = 100nF
- C_5 = 100nF
- C_1 = output capacitor of the SMPS
- C_4 = 10µF

4 - SCHEMATIC DIAGRAM

Figure 2 represents a schematic of the output circuit of a “classical” SMPS using a TL431 for voltage regulation. This circuit is modified to use the TSM101 and the final circuit is represented in Figure 3.

Figure 2 : SMPS Using a TL431 as Voltage Controller

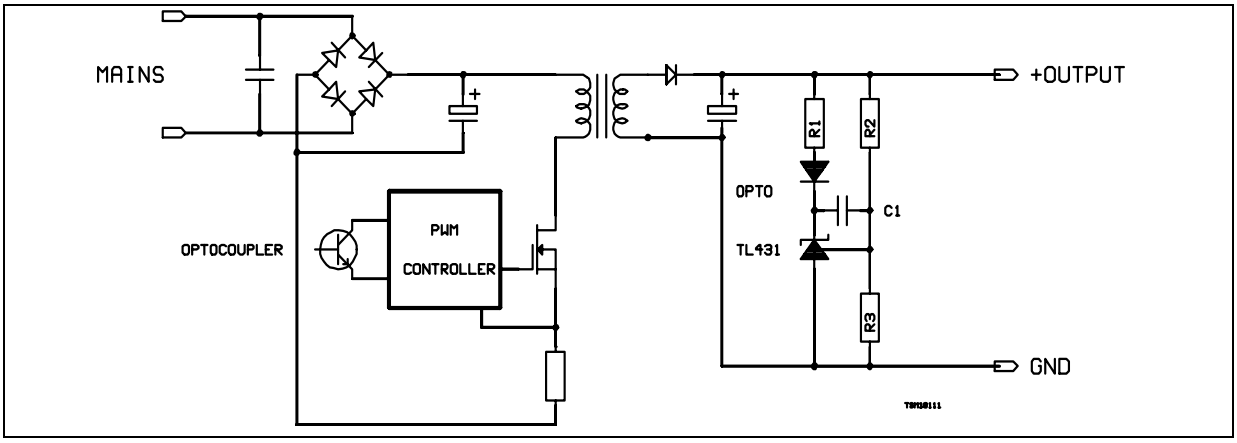
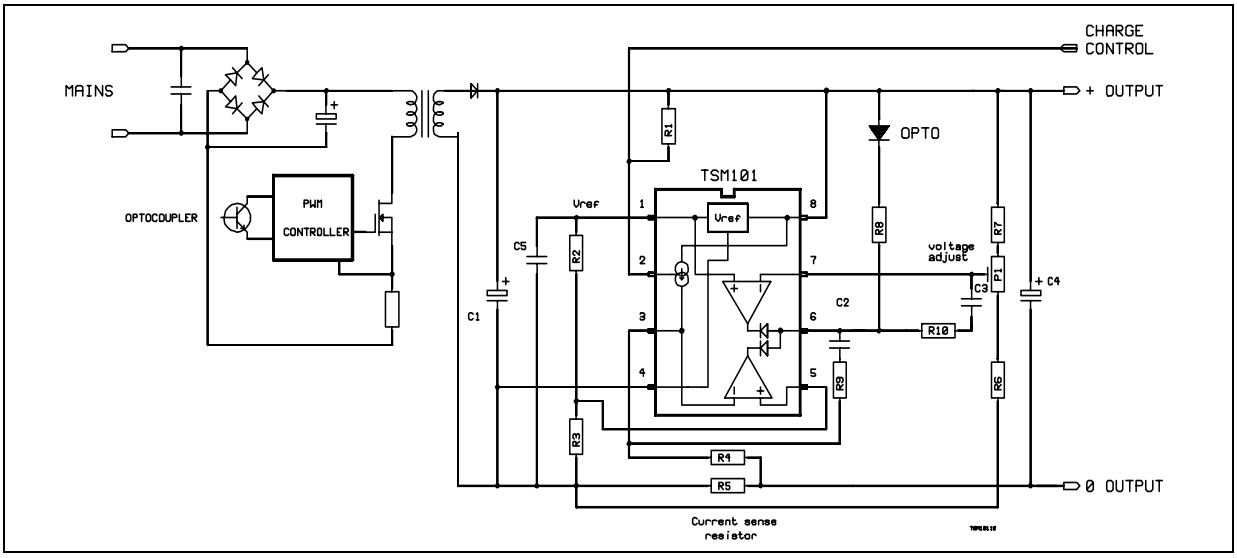


Figure 3 : SMPS Using the TSM101



5 - IMPROVEMENT

5.1. High frequency compensation

Two R-C devices (R_9, C_2 and R_{10}, C_3) are used to stabilize the regulation at high frequencies.
The calculation of these values is not easy and is a function of the transfer function of the SMPS.
A guess value for the capacitors C_2 and C_3 is 100nF.

5.2. Power supply for TSM101

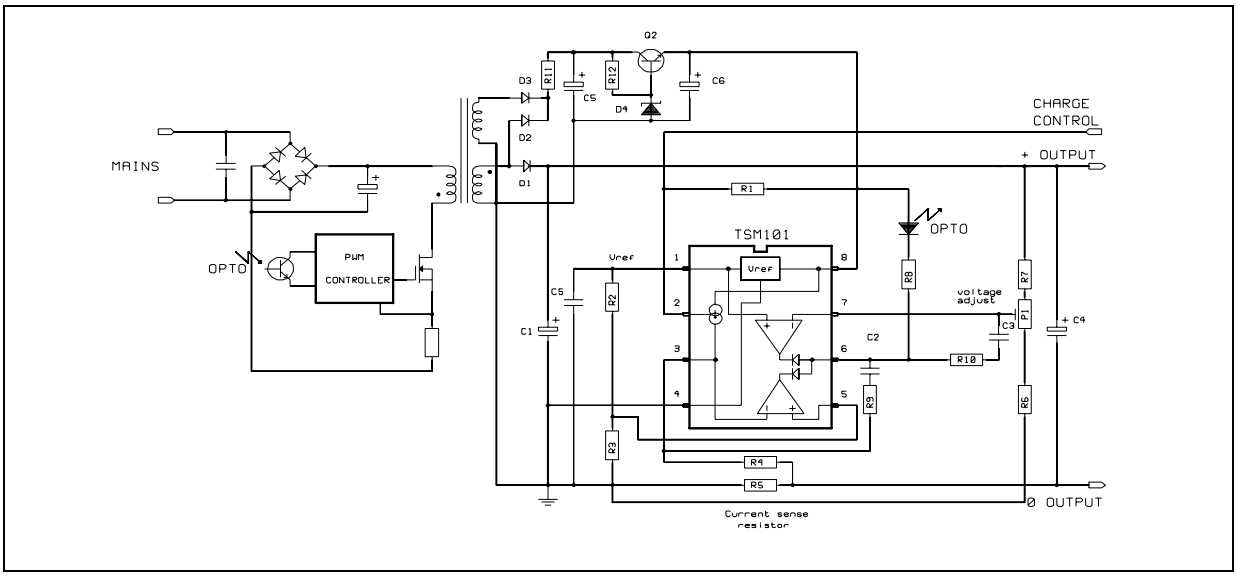
In applications requiring low voltage battery charge or when the charger is in current regulation mode, the output voltage can be too low to supply correctly the TSM101. The same problem occurs when the output is short-circuited.
A solution to provide a quasi constant supply voltage to the TSM101 is shown at Figure 4 : an auxiliary winding is added at the secondary side of the transformer.

This winding is forward coupled to the primary winding, the voltage across it is directly proportional to the mains rectified voltage, even if the flyback voltage is close to zero.

As this auxiliary winding is a voltage source, it is necessary to add a resistor (R_{11}) on the cathode of the rectifier (D_3) to limit the current.

A low cost regulator (Q_2 and Zener diode D_4) is used to power the TSM101. This is necessary with autoranging SMPS with wide input voltages, for example 90 to 240V without switching. In standard SMPS with voltage range from 200 to 240VAC or 100 to 130VAC, this regulator can be removed and replaced by the small power supply shown on Figure 5 (R_{aux}, C_{aux}, D_2).

Figure 4 : An Auxiliary Winding for TSM101 Power Supply



5.3 Higher Precision for the Voltage Control

The voltage drop through the sense resistor R_5 offsets the voltage measurement. In most battery charging applications, this offset is not taken into account because the error is negligible compared to the end-of-charge voltage due to the fact that the charging current value decreases drastically during the final phase of the battery charging.
But in other applications needing highest possible precision in voltage control, another connecting schematic is possible for TSM101 as shown on Figure 5.
In this schematic, the 0V reference is defined as the common point between the sense resistor, the 0V Output Voltage, the foot of the resistor bridge R_6/R_7, and the ground (pin 4) of the TSM101.
TSM101A (1% internal voltage reference precision) is required in such applications.

5.4 An example of application where the charging current is different according to the charging phase.

The following application includes a specific recommendation which requires that the charging current should be fixed to I_{ch1} = 800mA in normal charging conditions, and I_{ch2} = 200mA when the cell voltage is below V_{low}=2.5V to optimize the cell life-time.
Moreover, a Charging Status LED should be switched off when the cell voltage is above V_{high}=6.5V.
Figure 6 shows how this can easily be achieved using an additional dual comparator (type LM393) where the first operator (C_1) is used to activate the TSM101 internal current generator to offset the current measurement thanks to R_4, and the second (C_2) is used to switch the status LED off.

On Figure 6, the status signal is determined by voltage measurement, this could as well be achieved by current measurement.

If V_5 = 100mV is the maximum tolerable voltage drop through the sense resistor R_5 during normal charging conditions, then the following calculations apply :

Current Control :

$$R_5 = \frac{V_5}{I_{ch1}} = \frac{0.1V}{0.8A} = 125m\Omega$$

$$V_5 = V_{ref} \cdot \frac{R_3}{R_2 + R_3}$$

with $R_2 + R_3 \sim 12k\Omega$ and V_{ref} = 1.24V

$R_3 = 1k\Omega$, $R_2 = 11.4k\Omega$

$$V_5 = R_4 \cdot I_0 + R_5 \cdot I_{ch2}$$

therefore,

$$R_4 = \frac{V_5 - R_5 \cdot I_{ch2}}{I_0}$$

with I_0 = 1.4mA, $R_4 = 53.6\Omega$

$$V_{ref} = V_{low} \cdot \frac{R_{15}}{R_{14} + R_{15}}$$

with V_{low} = 2.5V and $R_{14} + R_{15} \sim 20k\Omega$

$R_{15} = R_{14} = 10k\Omega$

Figure 5 : Precise Output Voltage Control

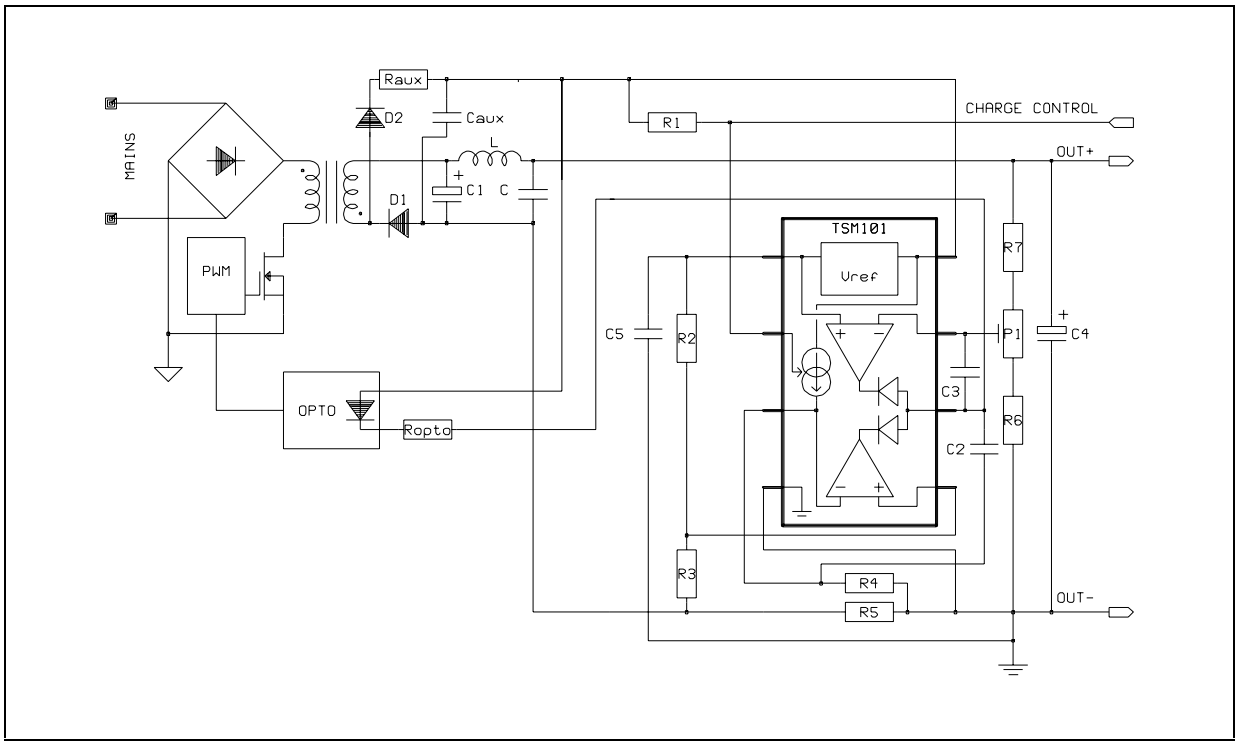
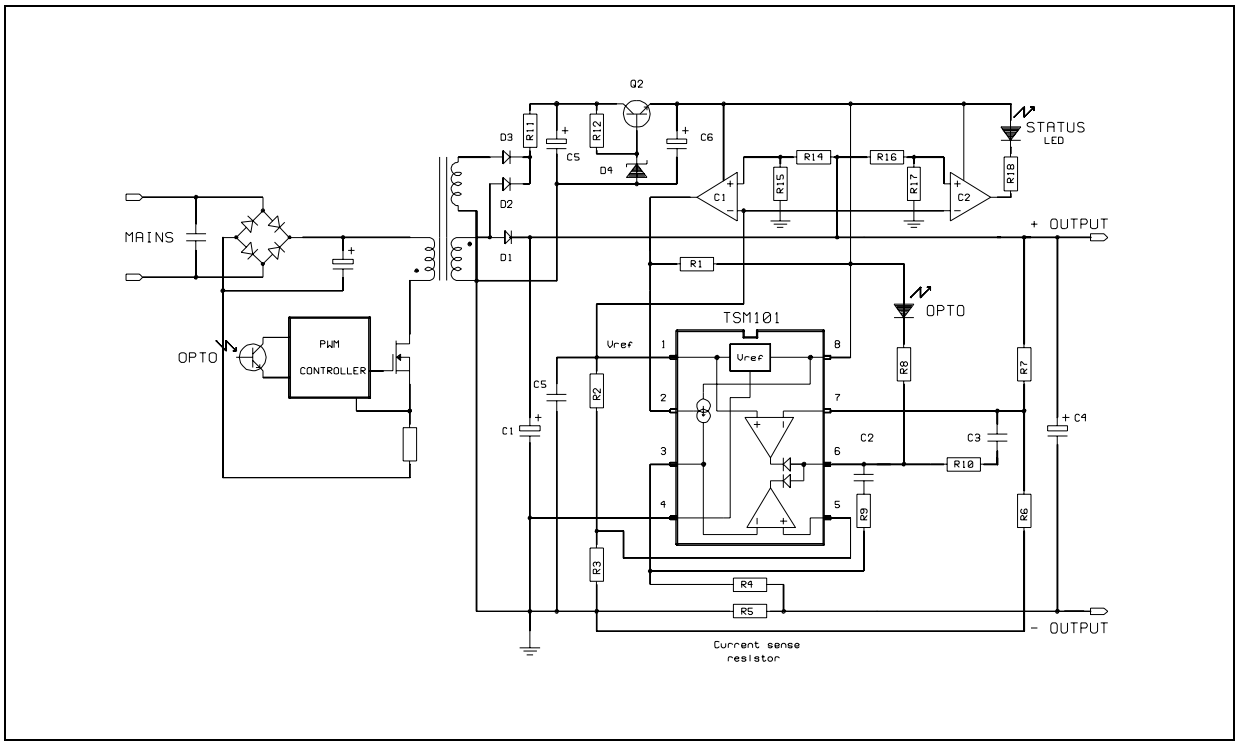


Figure 6 : Optimized Charging Conditions



EVALUATION BOARD - TECHNICAL NOTE

TSM101 integrates in the same 8 pin DIP or SO package

- ❑ one 1.24V precision voltage reference
- ❑ two operational amplifiers
- ❑ two diodes which impose a NOR function on the outputs of the operational amplifiers
- ❑ one current source which can be activated/ inhibited thanks to an external pin.

An immediate way to take advantage of the high integration and reliability of TSM101 is to use it as a voltage and current controller on power supplies secondary. The application note AN1283 describes precisely how to use TSM101 in an SMPS battery charger.

The TSM101 Evaluation Board is adaptable to any power supply or battery charger (SMPS or linear) as a voltage and current controller with minimal constraints from the user.

HOW TO USE THE TSM101 EVALUATION BOARD ?

The generic Electrical Schematic is shown on Figure 7. It represents an incomplete SMPS power supply where the primary side is simplified.

The **"IN+"and "IN-" power inputs** of the evaluation board should be connected directly to the power lines of the power supply secondary.

The **"Vcc" input** of the evaluation board should be connected to the auxiliary supply line.

In the case of an SMPS power supply, the **"Reg" output** of the evaluation board should be connected to the Optocoupler input to regulate the PWM block in the primary side. In the case of a linear power supply, the "Reg" output should be connected to the base of the darlington to regulate the power output.

A diode might be needed on the output of the evaluation board in the case of a battery charger application to avoid the discharge of the battery when the charger is not connected.

COMPONENTS CALCULATIONS

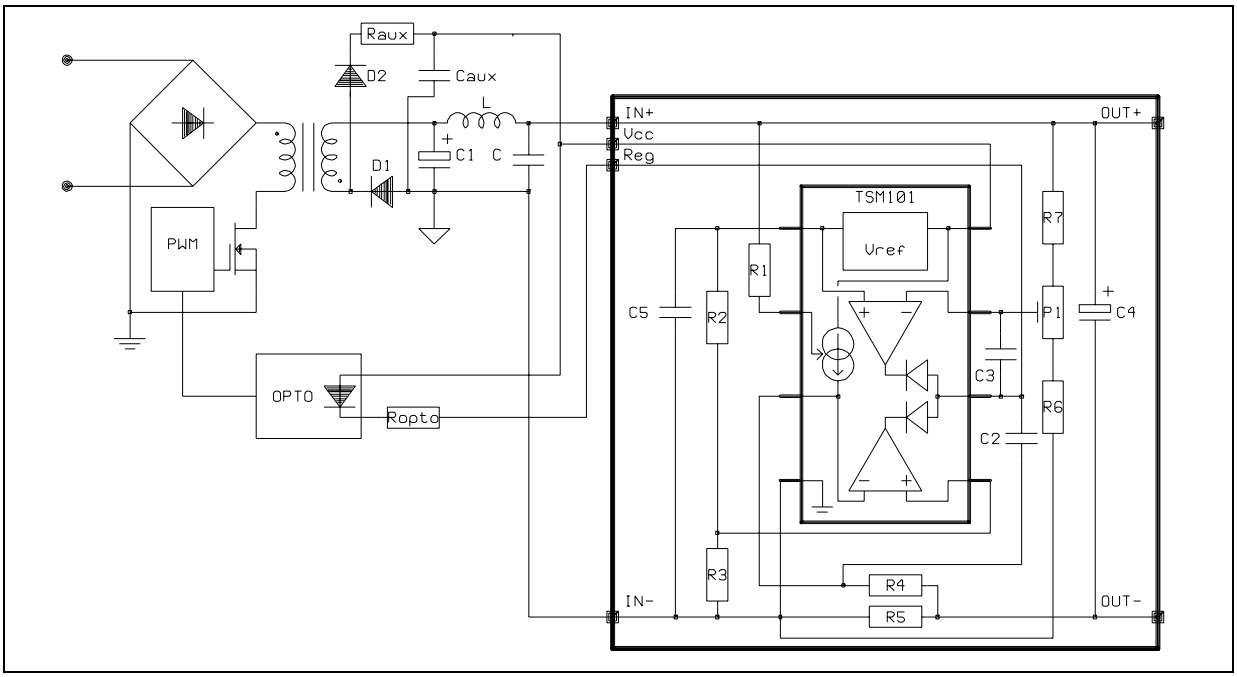
The **voltage control** is given by the choice of the resistor bridge R_6/R_7 (and the trimmer P_1) due to equation 1 :

- ❑ $V_{ref} = R_6/(R_6+R_7)xV_{out}$ **eq1**

where V_{ref} = 1.24V

The **current control** is given by the choice of the voltage drop through the sense resistor R_5 (to be linked to the nominal current of the application) and by the value of the sense resistor itself.

Figure 7: Evaluation board schematic



For medium currents (< 1A), a good value for the voltage drop through R_5 can be V_{sense} = 200mV (dissipation < 200mW).

The resistor bridge R_2/R_3 should be chosen following equation 2 :

❑ $V_{sense} = R_3 / (R_2+R_3) \times V_{ref}$ **eq2**

The total value of the resistor bridge should be in the range of the kW in order to ensure a proper charge for the voltage reference (in the range of the mA).

To set the current limit, the sense resistor R_5 should be chosen following equation 3 :

❑ $I_{lim} = V_{sense} / R_5$ **eq3**

The internal current generator (I_{sce}) can be used to offset the current limitation with a lower value.

This current generator is activated by connecting pin 2 to ground. It is inhibited if pin 2 is connected to the positive rail via the pull up resistor R_1.

The current offset is given by the choice of the resistor R_4.

If I_{lim1} is the current limit calculated in the previous paragraph, and I_{lim2} is the current limit that is to be set when pin 2 is connected to ground, R_4 should be chosen following equation 4 :

❑ $R_4 = (V_{sense} - I_{lim2} \times R_5) / I_{sce}$ **eq4**

where I_{sce} = 1.4mA

C_4 and C_5 are bypass capacitors used to smoothen the regulated outputs.

C_2 and C_3 are capacitors used for high frequency compensation.

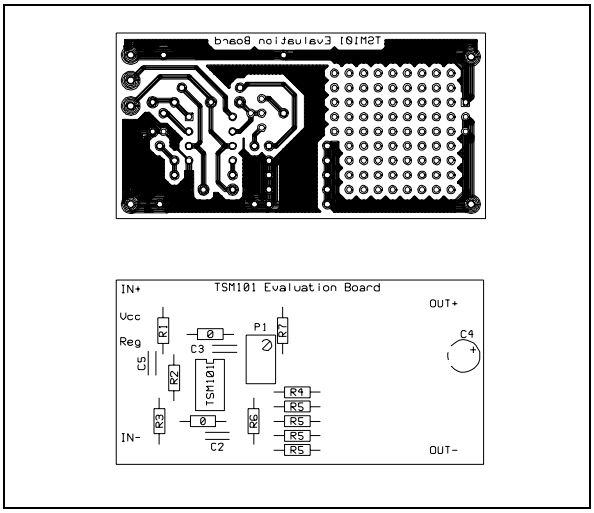
EXAMPLES OF COMPONENT LISTS

Table 1 summarizes a few examples of component lists to generate quickly 15V/700mA/ 200mA, 12V/1A/500mA or 8.2V/200mA/100mA voltage and current regulations.

Table 1

Voltage/ Current Control	15V 700mA 200mA	12V 1A 500mA	8.2V 200mA 100mA
R1	10kΩ	10kΩ	10kΩ
R2	1.2kΩ	1.2kΩ	1.2kΩ
R3	220Ω	220Ω	220Ω
R4	100Ω	68Ω	68Ω
R5	1.2Ωx4	0.8Ωx4	1Ωx4
R6	1kΩ	1kΩ	1kΩ
R7	12kΩ	8.2kΩ	5.6kΩ
P1	100Ω	100Ω	100Ω
2 straps	0Ω	0Ω	0Ω
C2	100nF	100nF	100nF
C3	100nF	100nF	100nF
C4	10µF	22µF	4.7µF
C5	100nF	100nF	100nF

Figure 8



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