AN2627
Application note

ST8R00 syncronous boost converter with output current cut-off function

Introduction

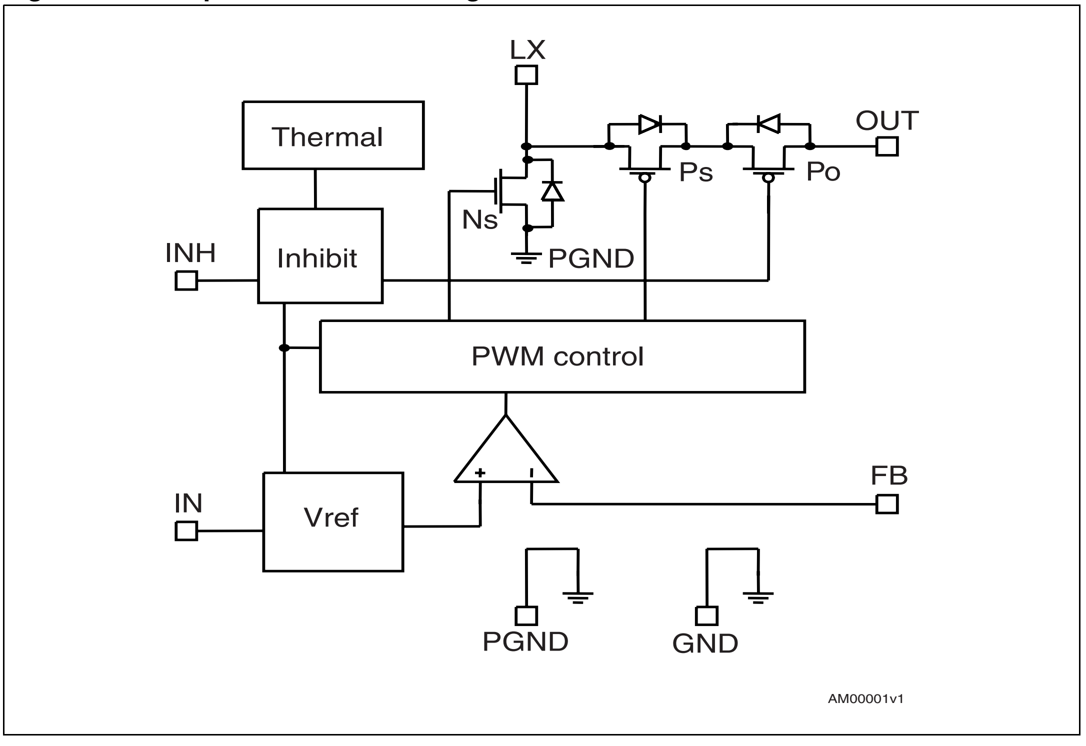
The ST8R00 family of synchronous step-up DC-DC converters with current output cut-off function provide up to 1 A over an input voltage range of 4 V to 6 V and an output voltage range of 6 V to 12 V.

The high switching frequency (1.2 MHz) allows the use of tiny surface-mount components. Along with the resistor divider to set the output voltage value, an inductor and two capacitors are required. A low output ripple is guaranteed by the current mode PWM topology and by the use of low ESR surface-mounted ceramic capacitors.

The device is available in two versions: burst mode (ST8R00) and continuous mode (ST8R00W).

The ST8R00 devices are thermal protected and available in the DFN8 4x4 package.

Figure 1. Simplified schematic diagram



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1 ST8R00 description

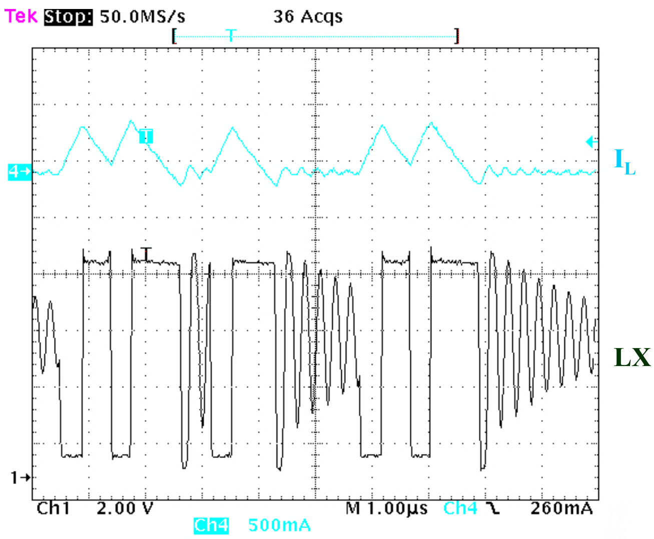
The ST8R00 is a family of adjustable current mode PWM synchronous step-up DC-DC converters with internal 1 A power switch. It represents a complete 1 A switching regulator with internal compensation which eliminates the need for additional components.

The two devices in the family, the ST8R00 and ST8R00W, operate at light load in two different ways. The ST8R00 works in power-save mode to achieve good efficiency, as shown in *Figure 2*. The ST8R00W, in order to guarantee the lowest switching ripple, operates in PWM (pulse width modulation) mode as show in *Figure 3* and *Figure 4*.

At medium and high load current, both versions operate in PWM mode.

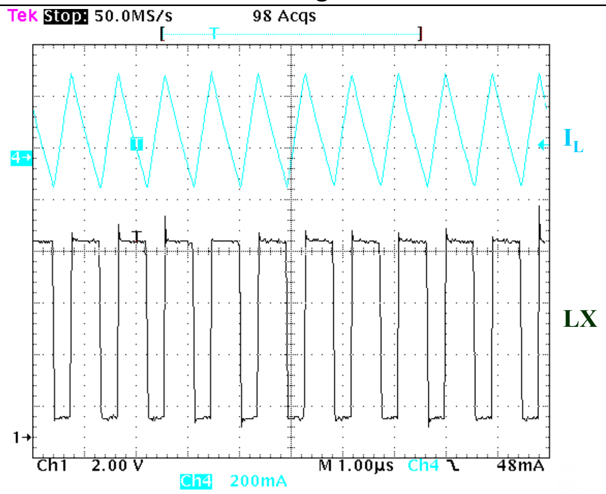
The thermal shutdown block turns off the regulator when the junction temperature exceeds 150 °C (typ), and the cycle-by-cycle current limiting provides protection against overcurrent sink.

Figure 2. ST8R00 inductor current at light load



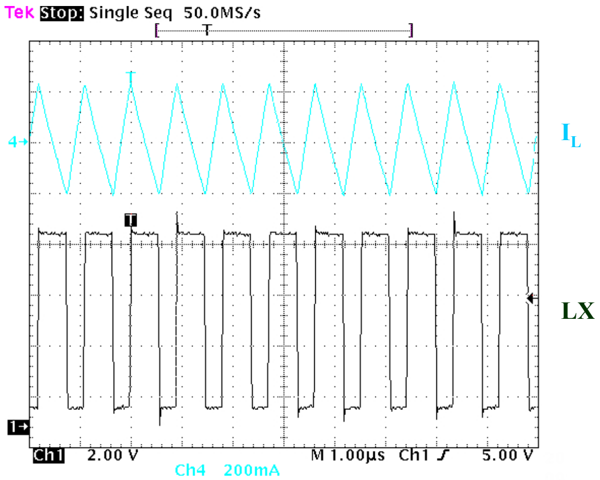
V_{IN}=5 V, V_{OUT}=8 V, I_{OUT}=60 mA, Ch1=LX, Ch4=I_L

Figure 3. ST8R00W inductor current at light load



V_{IN}=5 V, V_{OUT}=8 V, I_{OUT}=60 mA, Ch1=LX, Ch4=I_L

Figure 4. ST8R00W inductor current at no load



V_{IN}=5 V, V_{OUT}=8 V, no load Ch1=LX, Ch4=I_L

For proper functioning of the device, only a few components are required: an inductor, two capacitors and the resistor divider. The inductor chosen must not saturate at the operating peak current. Its value should be selected taking into account that a large inductor value reduces output voltage ripple, while a smaller inductor can be selected when it is important to reduce package size and the total cost of the application. Finally, the ST8R00 family has been designed to work properly with X5R or X7R SMD ceramic capacitors both at the input and at the output. These types of capacitors, thanks to their very low series resistance (ESR), minimize the output voltage ripple. Other low ESR capacitors can be used in accordance with application requirements without compromising the correct functionality of the device.

This device features an output current cut-off function. Two P-channel MOSFETs in a back-to-back configuration, as shown in *Figure 5*, stop the output current when the inhibit is low (*Figure 6*).

Figure 5. ST8R00 cut-off block

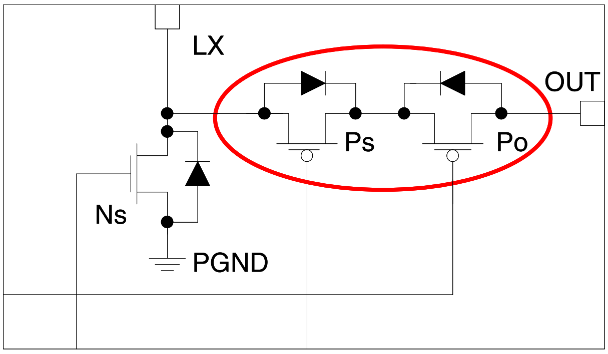


Figure 6. Current cut-off function

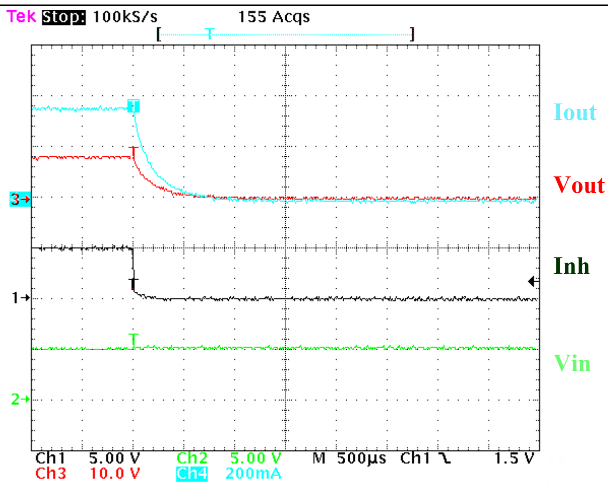
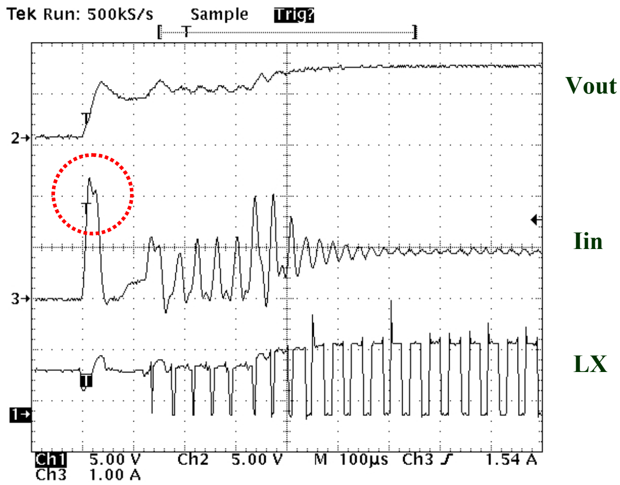


Figure 7 shows the in-rush current at start-up. Initially, the C_{OUT} capacitor is completely discharged and the current limitation is due only to the equivalent series resistor of the inductor, the power MOSFET parasitic diode and the cut-off MOSFETs' $R_{DS(ON)}$. As soon as the output voltage reaches the input voltage level, the device begins to switch and the current is limited cycle by cycle.

Figure 7. Inrush current



V_{IN}=4.5 V, V_{OUT}=7 V, V_{INH} from 0 V to 3 V, R_{LOAD}=13 Ω, L=10 µH, C_{IN}=C_{OUT}=10 µF

1.1 Inhibit function

The ST8R00 family of devices also include an inhibit function (pin 6). When the INH voltage is higher than 2 V, the device is ON and if it is lower than 0.8 V, the device is OFF.

The INH pin does not have an internal pull-up, which means that the pin cannot be left floating.

If the inhibit function is not used, the INH pin must be connected to V_{IN} as in the schematic in *Figure 8* below.

Figure 8. ST8R00 application schematic

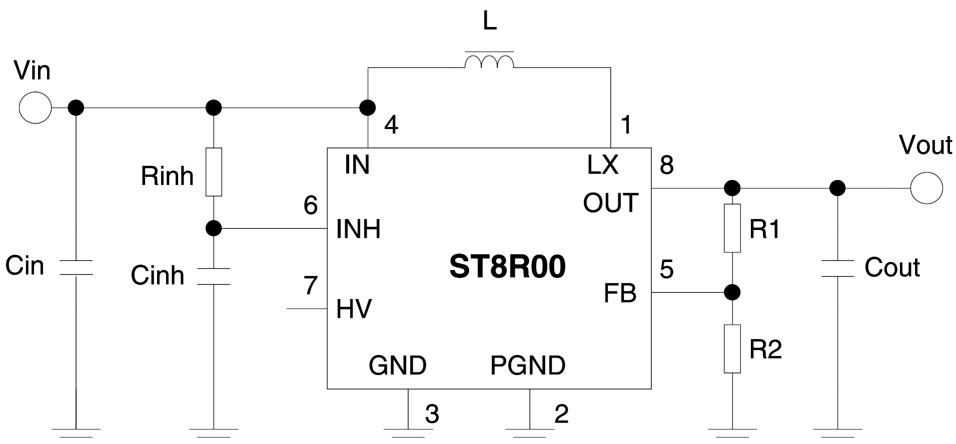
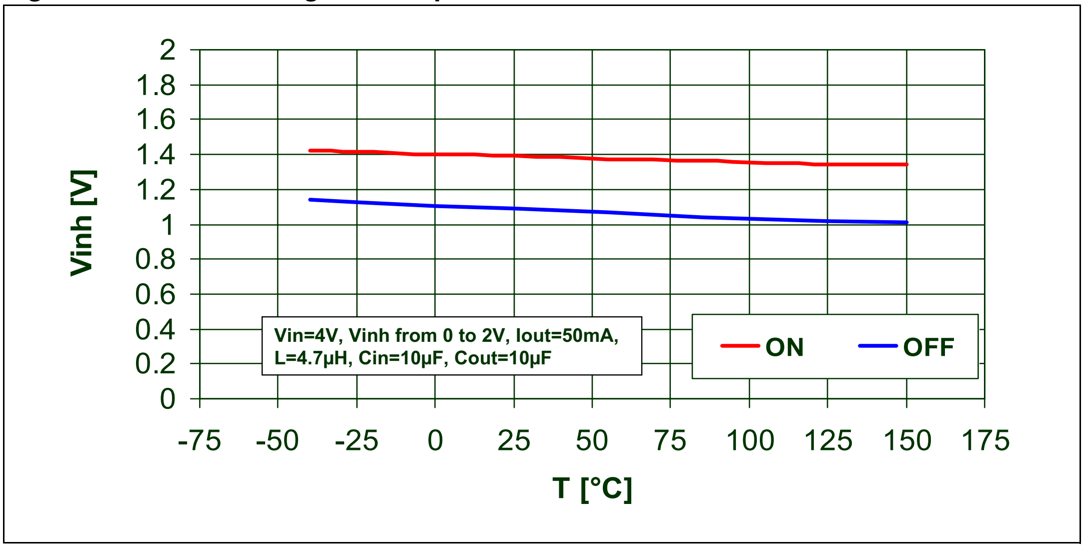


Figure 9. Inhibit voltage vs. temperature

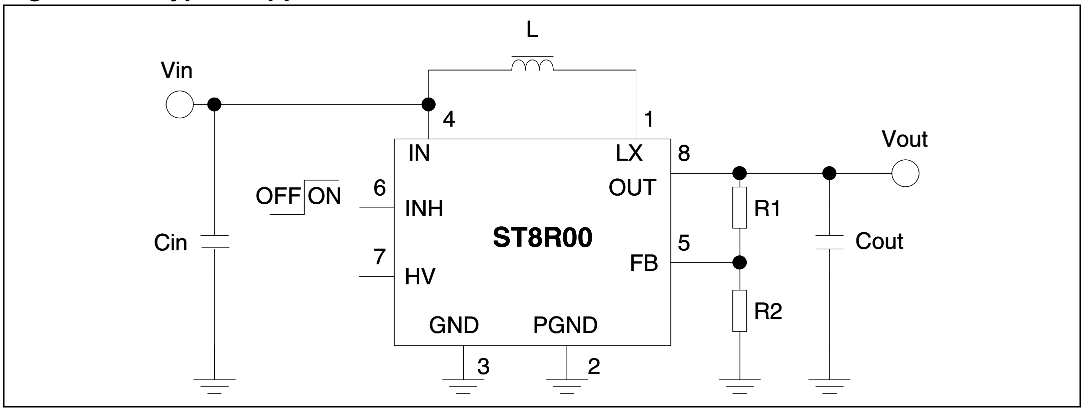


2 Selecting components for applications

This section provides information to assist in the selection of the most appropriate components for applications.

Figure 10 shows a typical application schematic diagram.

Figure 10. Typical application schematic



2.1 Output voltage selection

The output voltage can be adjusted from 6 V up to 12 V by connecting a resistor divider between the output and the FB pin.

The resistor divider should be chosen in accordance with the following equation:

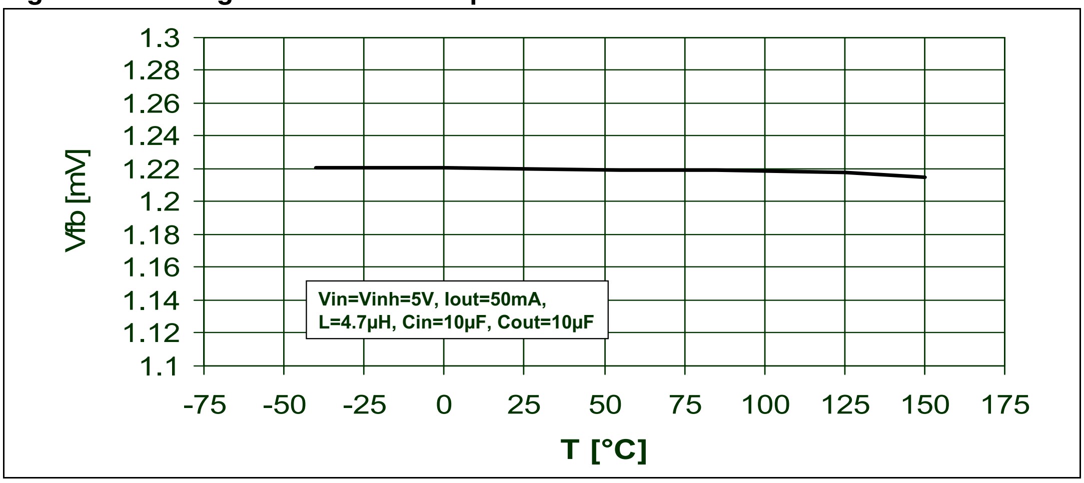
Equation 1

$$V_{out} = V_{FB}\left[1 + \frac{R_1}{R_2}\right] \quad \text{with} \quad V_{FB} = 1.22\ \text{V}$$

The feedback voltage versus temperature is shown *Figure 11* below.

It is recommended to use a resistor with a value in the range of 10 kΩ to 100 kΩ. Lower values can be suitable as well, but will increase current consumption.

Figure 11. Voltage feedback vs. temperature



2.2 Input capacitor

The input capacitor must be able to provide AC ripple current to the inductor and to withstand the maximum input operating voltage.

Another important function of the input capacitor is to limit noise and therefore the interference with the other blocks connected to the same network.

The quality of these capacitors must to be quite high to minimize the power dissipation generated by the internal ESR, thereby improving system reliability and efficiency.

Various capacitors can be considered:

- Ceramic capacitors - These capacitors usually have a higher RMS current rating for a given physical dimension (due to the very low ESR). The drawback is the high cost of capacitors with very large values.
- Electrolytic capacitor - The availability of small size tantalum capacitors with very low ESR is increasing. However, they are subject to thermal damage if subjected to very high current during charge. Since they can, in fact, be subjected to high surge current when connected to the power supply, it is better to avoid using this type of capacitor for the input filter of the device. Aluminum capacitors are not the best choice due to their high ESR.

2.3 Inductor

The inductor value is very important because it establishes the ripple current. The approximate inductor value is obtained with the following formula:

Equation 2

$$L = \frac{Vin}{\Delta I_L} \cdot T_{ON}$$

where T_{ON} is the ON time of the internal switch, given by $D \cdot T_{SW}$. The ripple current, ΔI_L, is usually fixed at 20-40% of I_{IN_MAX}.

Equation 3

$$I_{IN\_MAX} = \frac{I_{OUT\_max} \cdot Vout}{Vin \cdot \eta}$$

where η is the efficiency.

2.4 Output capacitor

The output capacitor is very important to satisfy the output voltage ripple requirement. To reduce the output voltage ripple, a low ESR capacitor is required.

The output voltage ripple (V_{RIPPLE}), in continuous mode is:

Equation 4

$$V_{RIPPLE} = I_{out} \cdot \left(ESR + \frac{(V_{out} - V_{in})}{V_{out} \cdot C_{out} \cdot F_{SW}}\right)$$

where F_{SW} is the switching frequency.

2.5 Layout considerations

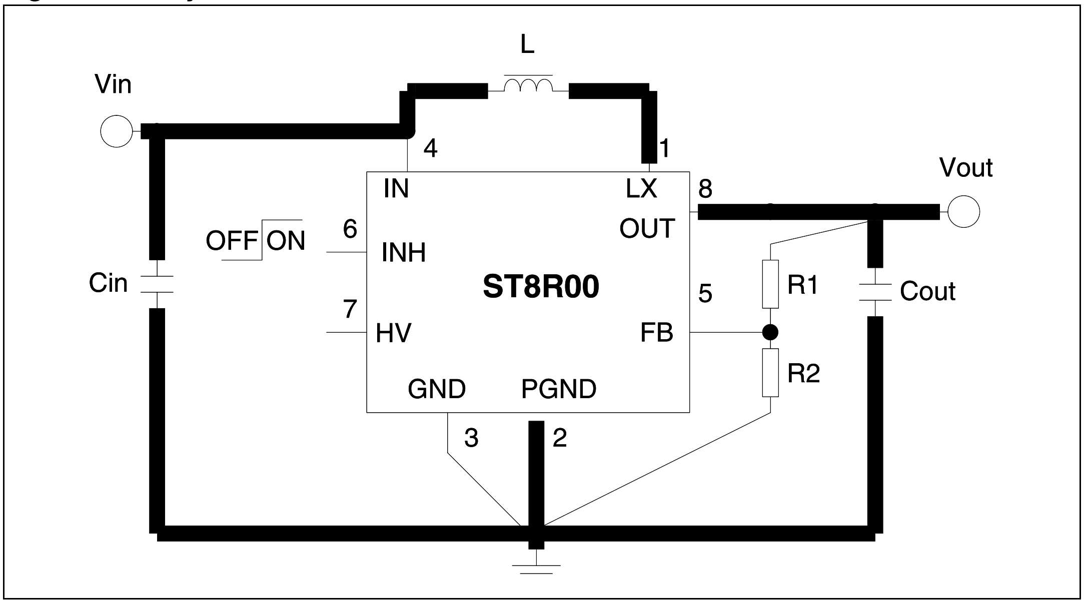
Due to the high switching frequency and peak current, the layout is an important design step for all switching power supplies. If the layout is not done carefully, important parameters such as efficiency and output voltage ripple could be out of specification.

Short, wide traces must be implemented for main current and for power ground paths as shown in bold in *Figure 12*. The input capacitor must be placed as close as possible to the IC pins as well as the inductor and output capacitor.

A common ground node minimizes ground noise, as shown in *Figure 12*.

The HV pin must be floating or connected to GND and the exposed pad of the package must be connected to the common ground node.

Figure 12. Layout considerations



3 Thermal considerations

The dissipated power of the device is related to three different sources:

- Switching losses due to the (not negligible) $R_{DS(ON)}$. These are equal to:

Equation 5

$$P_{ON\_N} = R_{DSON\_N} \cdot [I_{OUT} / (1-D)]^2 \cdot D$$

and

Equation 6

$$P_{ON\_P} = R_{DSON\_PEQ} \cdot I_{OUT}^2 \cdot (1-D)$$

where D is the duty cycle of the application and $R_{DS(ON)\_PEQ}$=$R_{DS(ON)\_PS}$+$R_{DS(ON)\_PO}$.

Note: the duty cycle is theoretically given by:

$$1-\frac{V_{in}}{V_{out}}$$

but in practice it is quite higher than this value to compensate for the losses of the overall application. For this reason, the switching losses related to the $R_{DS(ON)}$ increase compared to an ideal case.

- Switching losses due to its turning on and off. These are calculated using the following equation:

Equation 7

$$P_{SW} = V_{IN} \cdot I_{OUT} \cdot \frac{(t_{ON} + t_{OFF})}{2} \cdot F_{SW} = V_{IN} \cdot I_{OUT} \cdot t_{R\text{-}F} \cdot F_{SW}$$

where t_{ON} and t_{OFF} are the overlap times of the voltage across the power switch and the current flowing into it during the turn-on and turn-off phases. $t_{R\text{-}F}$ is the equivalent switching time.

- Quiescent current losses:

Equation 8

$$P_Q = V_{IN} \cdot I_Q$$

where I_Q is the quiescent current.

The overall losses are:

Equation 9

$$P_{TOT} = R_{DSON\_N} \cdot (I_{OUT} / 1-D)^2 \cdot D + R_{DSON\_PEQ} \cdot I_{OUT}^2 \cdot (1-D) + V_{IN} \cdot I_{OUT} \cdot t_{R\text{-}F} \cdot F_{SW} + V_{IN} \cdot I_Q$$

The junction temperature of device will be:

Equation 10

$$T_J = T_A + R_{thJA} \cdot P_{TOT}$$

where T_A is the ambient temperature and R_{thJA} is the thermal resistance junction-to-ambient.

4 Demonstration board usage recommendation

The demonstration board shown in *Figure 13* is provided with a Kelvin connection, so for each pin there are two lines available: one used to supply or sink current, and the other used to perform the needed measurement.

The ST8R00 inhibit pin does not have an internal pull-up, so the inhibit pin cannot be left floating.

Figure 13. The ST8R00 demonstration board

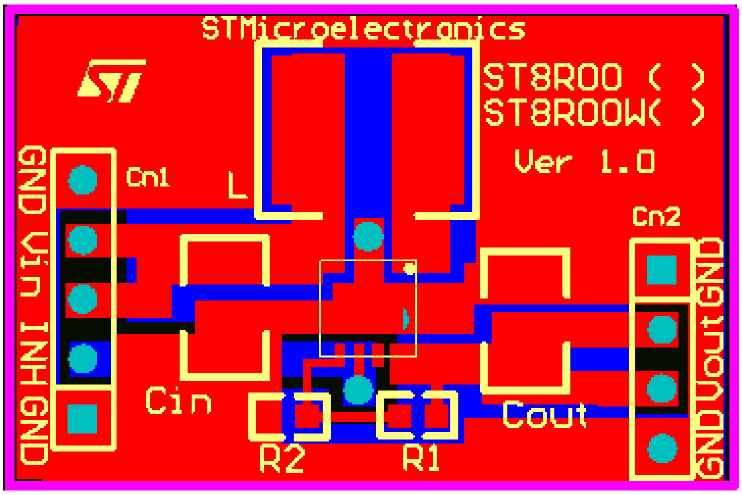
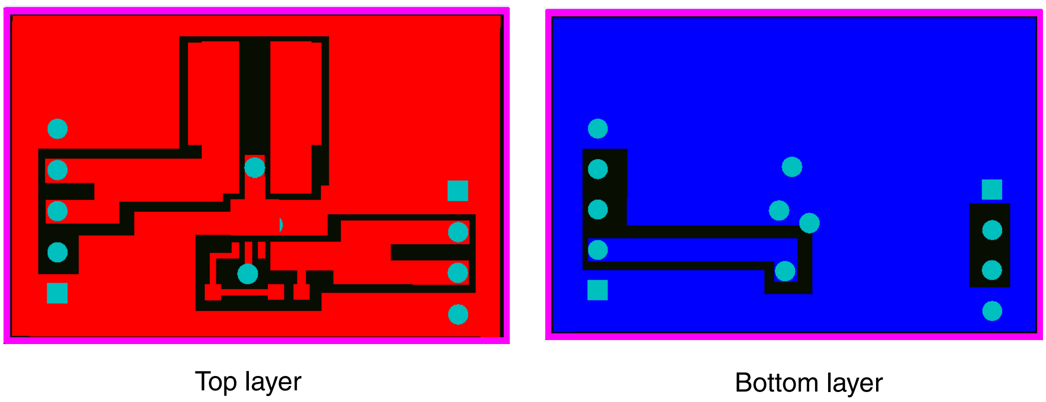


Figure 14. Demonstration board layers



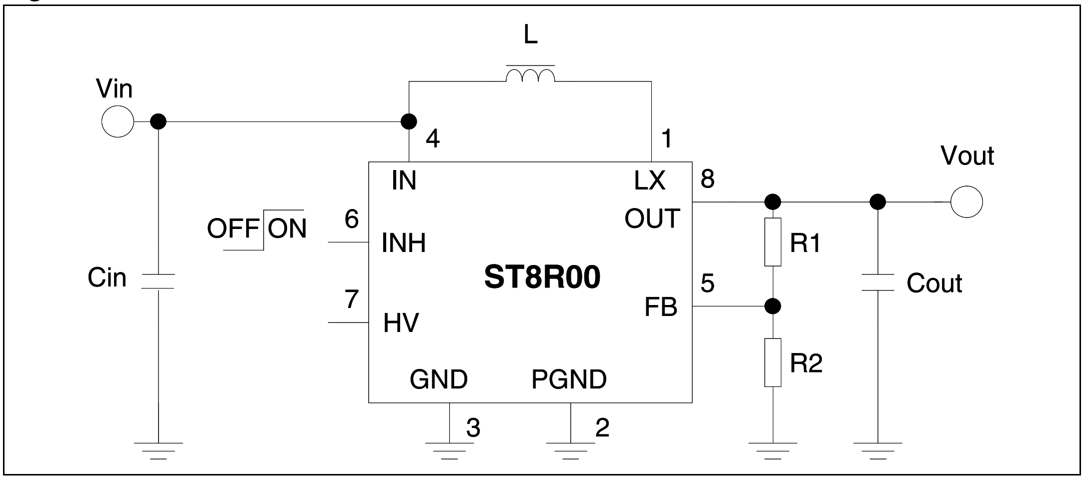
The board has one inhibit pin available, located on the top left of the board.

The inhibit pin can be used to supply an external voltage higher than 2 V to turn on the device, or an external voltage lower than 0.8 V to turn off the device.

4.1 External component selection

Figure 15 shows the schematic diagram of the demonstration board.

Figure 15. Demonstration board schematic



In order to obtain the needed output voltage, the resistor divider must be selected based on the following formula:

Equation 11

$$V_{out} = V_{FB}\left[1 + \frac{R1}{R2}\right] \quad \text{with} \quad V_{FB} = 1.22\ V$$

Table 1. Recommended resistor divider

V_{out}	R1	R2
8 V	56 kΩ	10 kΩ
9.5 V	68 kΩ	10 kΩ

The resistors in *Table 1* represent a good compromise in terms of current consumption and minimum output voltage.

4.1.1 Capacitor selection

It is possible to use any X5R or X7R ceramic capacitor:

- C_{IN}=10 µF (ceramic) or higher
- C_{OUT}=10 µF (ceramic) or higher. It is possible to put several capacitors in parallel to reduce the equivalent series resistance and improve the ripple present in the output voltage.

4.1.2 Inductor selection

Due to the high (1.2 MHz) frequency, it is possible to use very small inductor values. In the demonstration board, the device was tested with inductors in the range of 1 µH to 10 µH, with very good efficiency performance (see *Figure 18* and *Figure 19*).

Because the device is able to provide an operating output current of 1 A, we strongly recommend the use of inductors capable of managing at least 3.5 A.

Figure 16. Efficiency vs. output current

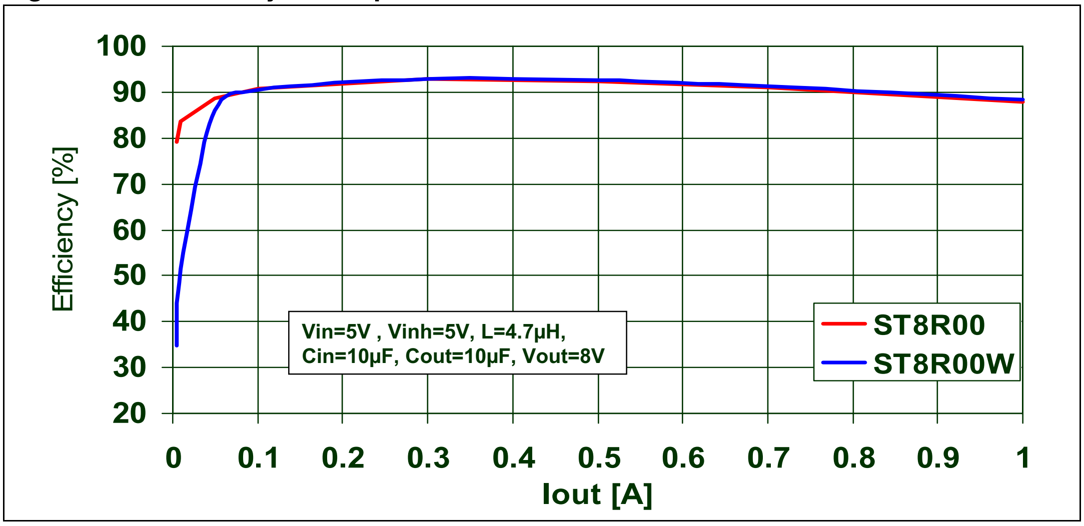


Figure 17. Efficiency vs. output voltage

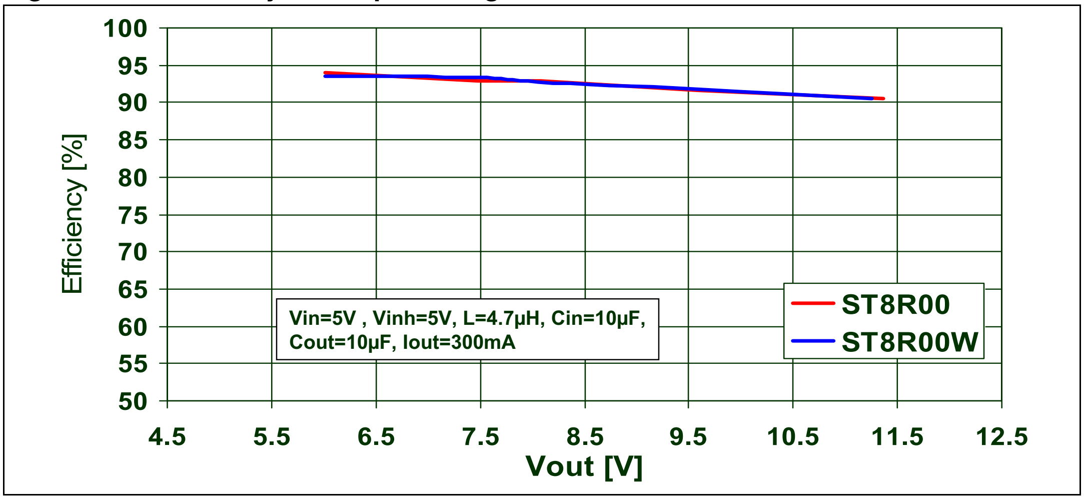


Figure 18. ST8R00 efficiency vs. inductor

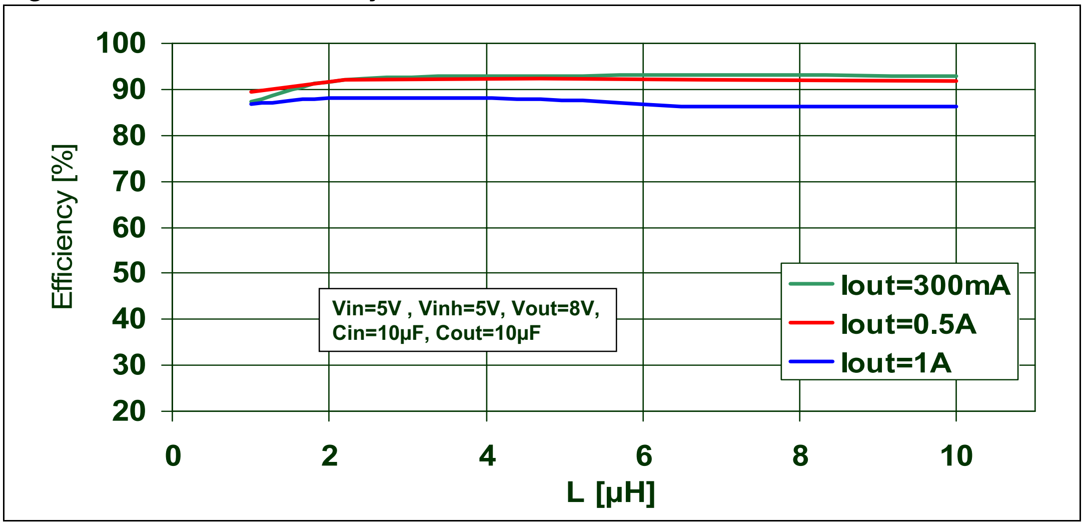
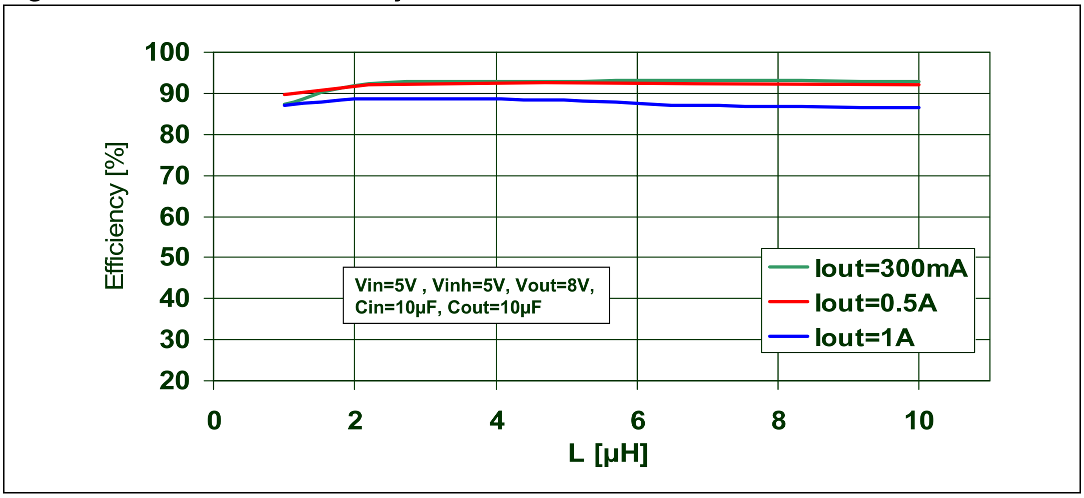


Figure 19. ST8R00W efficiency vs. inductor



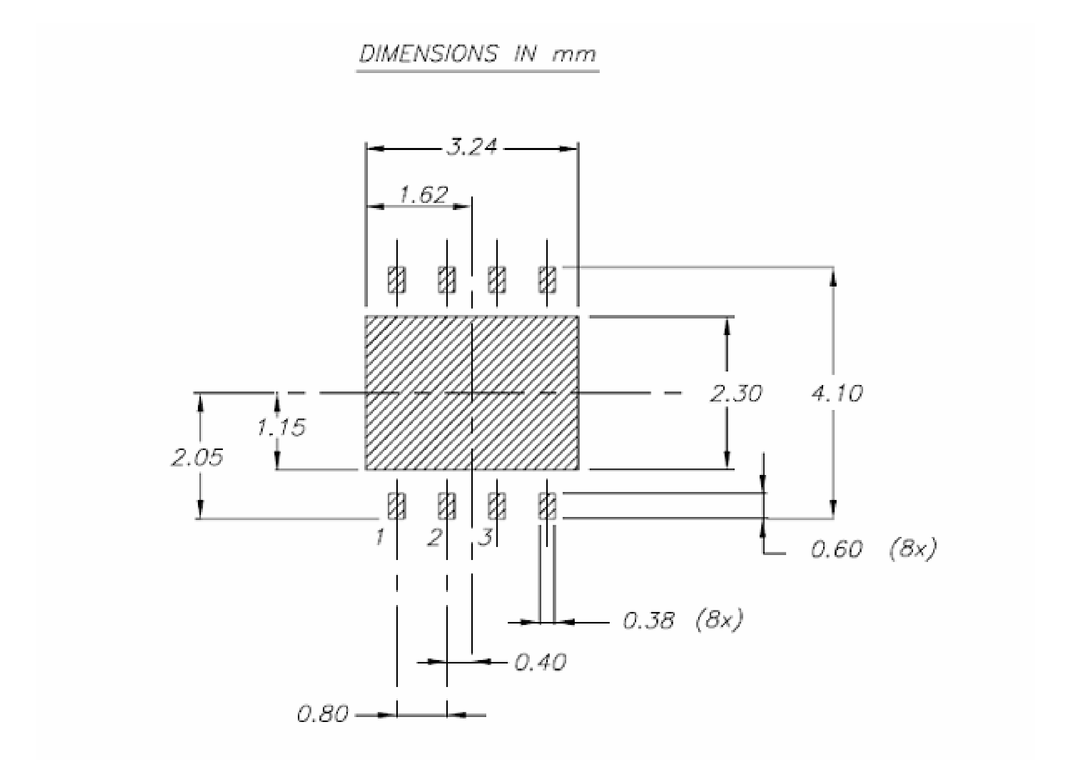
5 BOM with most-used components

Table 2. Bill of materials

Name	Value	Material	Manufacturer	Part numbers
C_{IN}	10 µF	Ceramic	Murata	GRM31CR61E106KA12B
C_{OUT}	10 µF	Ceramic	Murata	GRM31CR61E106KA12B
L	4.7 µH		Coiltronics	DR73-4R7

6 Footprint recommended data

Figure 20. DFN8 4x4 recommended footprint



7 Revision history

Table 3. Document revision history

Date	Revision	Changes
13-May-2008	1	Initial release
03-Dec-2009	2	Modified *Equation 9: on page 12*.