AN2650
Application note

L9942 stepper motor driver for bipolar stepper motors

Introduction

The L9942 is an integrated stepper motor driver for bipolar stepper motors. The device is designed for automotive applications, such as headlamp leveling, steerable lights and adaptive front lighting. Other applications, such as ventilation and air conditioning flap and throttle positioning are also possible uses for the L9942.

The device drives bipolar stepper motors with high-efficiency and smooth operation. Micro-stepping is the preferred mode to provide low-noise operation since this technique eliminates the effects of mechanical resonances, which can lower the motor torque.

A motor stall detection capability allows position alignment without an external sensor, while its step counter is addressable via an SPI as well as by a separate input, to prevent the SPI overloading when running multiple motors simultaneously.

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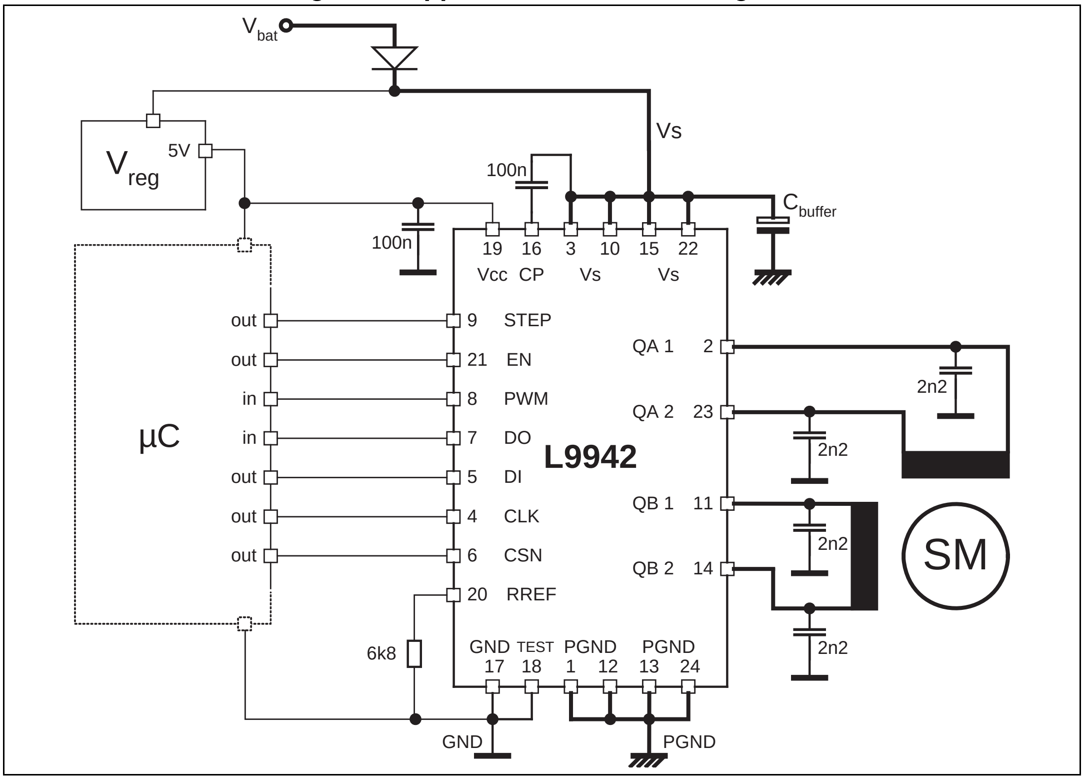
1 Typical application schematic

Figure 1. Application schematic diagram



The L9942 is driven by a microcontroller via the SPI (DO, DI, CLK, and CSN), STEP and EN pins. Additional information is provided from the PWM pin.

The stepper motor driver is supplied from a 5 V voltage regulator and the reverse polarity protected Vs. It is necessary to use a stabilization capacitor (with a minimum value of minimum 100 nF) as close as possible at the Vcc pin. For the stabilization of the Vs supply pin and to absorb motor energy, an electrolytic capacitor C_{buffer}, with a minimum value as calculated in *Section 1.1*, must be used.

Because the motor currents are supplied via the Vs-pins, all Vs-pins must have a low ohmic connection to the supply voltage Vs. For the same reason, all GND and PGND pins must have a low ohmic connection to the system ground. A star ground concept with separate lines for GND and PGND is recommended.

At the charge pump pin, a capacitor with 100 nF to Vs is recommended.

To improve the EMI behavior, it is recommended to have 2.2 nF capacitors as close as possible to the motor output pins, Qxy. Short motor connection wires also improve the EMI behavior.

The internally-used reference voltage depends upon the value of the reference resistor, positioned between the pin RREF and GND. Consequently, the precision of the L9942 depends upon the value of the reference resistor. One possible value for this resistor is 6.8 kΩ.

Due to the structure of the BCD process, the slug of the device is connected internally to PGND and must also be connected externally to PGND.

1.1 Calculation of the buffer capacitor C_{buffer}

The stepper motor driver L9942 is usually designed in an environment similar to that shown in *Figure 1*.

During motor operation, electrical energy is stored in the motor coils. If the motor shuts down, this energy is fed back to the supply voltage Vs. Thus, there is a voltage increase at Vs, which may cause an electrical overstress of the L9942. To avoid damage to the L9942, the value of the buffer capacitor C_{buffer} must be chosen carefully.

The energy balance can be calculated from:

$$\frac{1}{2} \cdot C_{buffer} \cdot V_{s1}^2 + \frac{1}{2} \cdot L_{motor} \cdot I_{motor}^2 \approx \frac{1}{2} \cdot C_{buffer} \cdot V_{s2}^2$$

$$V_{s1}^2 + \frac{L_{motor}}{C_{buffer}} \cdot I_{motor}^2 = V_{s2}^2$$

$$V_{s2} = \sqrt{V_{s1}^2 + \frac{L_{motor}}{C_{buffer}} \cdot I_{motor}^2}$$

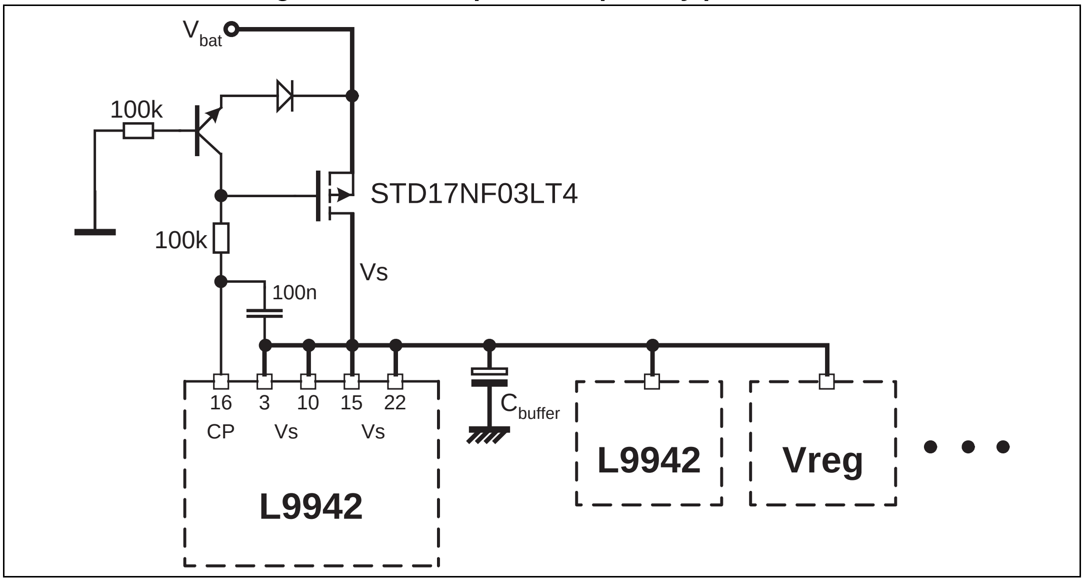
From this equation, it is possible to conclude:

- The voltage Vs2 must not exceed the maximum rating of the L9942
- If an over voltage shut down must be avoided, the voltage Vs2 must not exceed the minimum over voltage threshold.

Note: As a general recommendation, STMicroelectronics recommend a minimum buffer capacitor of 47 µF. The ripple at Vs during normal motor operation should be between 5% and 10%.

1.2 Low drop reverse polarity protection

Figure 2. Low drop reverse polarity protection



As shown in *Figure 2* the charge pump pin can be used for a low drop reverse polarity protection. The charge pump pin can also be used for other devices in the same application. Because of the additional gate capacity, the charge pump ramps up more slowly than without the additional MOSFET gate.

2 Shorted coil detection

During free-wheeling time, the L9942 can use several decay modes that are programmable by the SPI.

However, only on **Auto decay, fast decay without delay time** it is possible to detect shorted coil because, during free-wheeling time, both opposite transistors (HS and LS) are switched on and high current can rise. During free wheeling the current in the output stage is monitored, but not regulated, with PWM. Because of this, the short overcomes the over current filter time and can be detected.

In other decay modes, the decay can periodically change during wheeling of the motor (for example, every 200 ms) to Auto decay, fast decay without delay time for few microseconds and than change it back to previous value. This can be done in one clock step.

The decay mode cannot be changed at all values of the phase counter because fast decay is not active during the whole period but only during decreasing current phase in the coil (during the rising current phase, the coil is active slow decay mode).

A detailed explanation of Auto decay, fast decay without delay time for all step modes is given in *Figure 3*.

Figure 3. Stepping modes (Auto decay mode, fast decay without delay time)

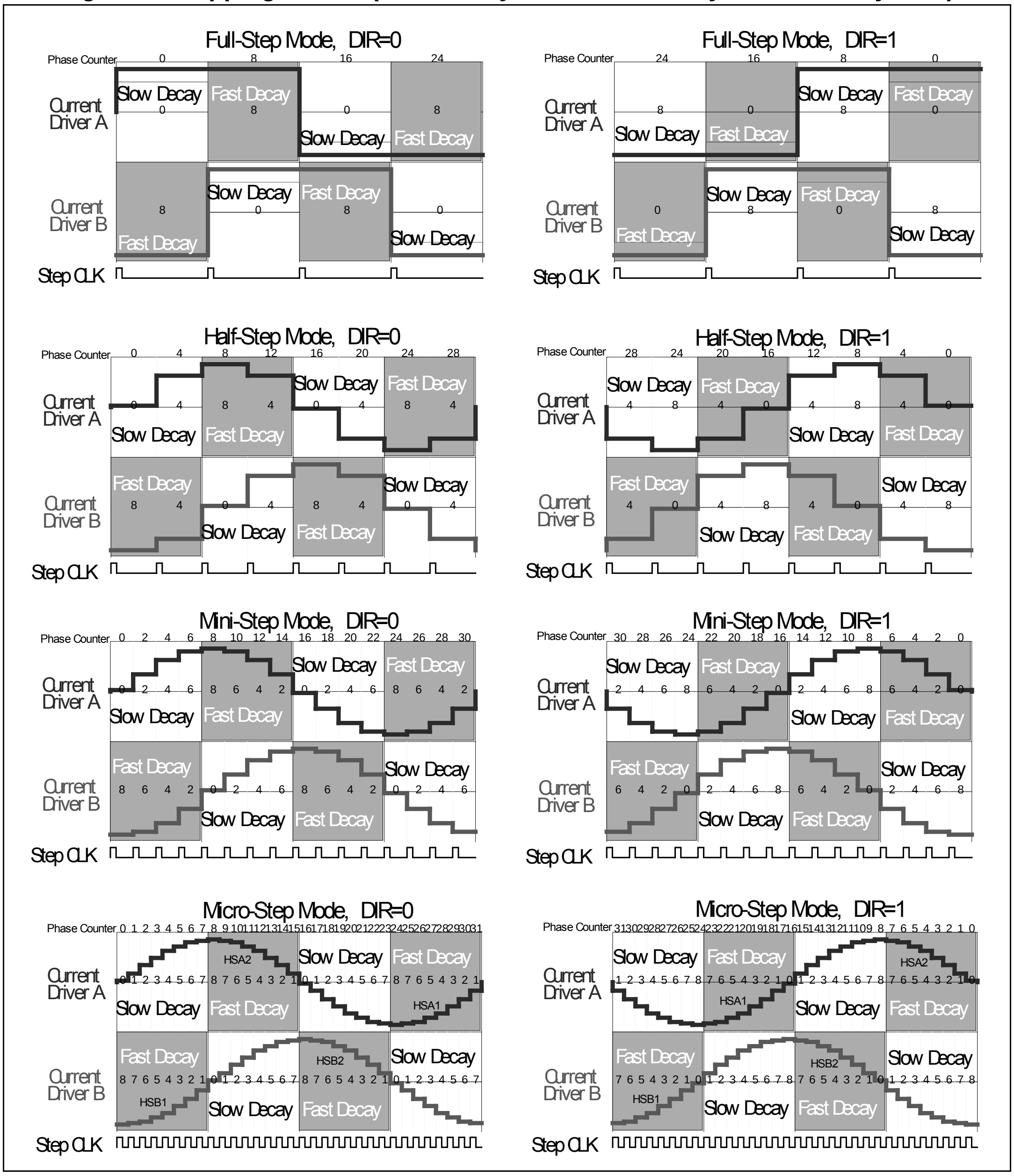


Table 1 shows Phase Counter values where fast decay is active.

Table 1. Phase counter values for fast decay

Step Mode	Bridge	DIR=0	DIR=1
Full step	A	(8) (24)	(16(1)) (0(1))
	B	(0) (16)	(24(1)) (8(1))
Half step	A	(8, 12) (24, 28	(20, 16(1)) (4, 0(1))
	B	(0, 4) (16, 20)	(28, 24(1)) (12, 8(1))

Table 1. Phase counter values for fast decay (continued)

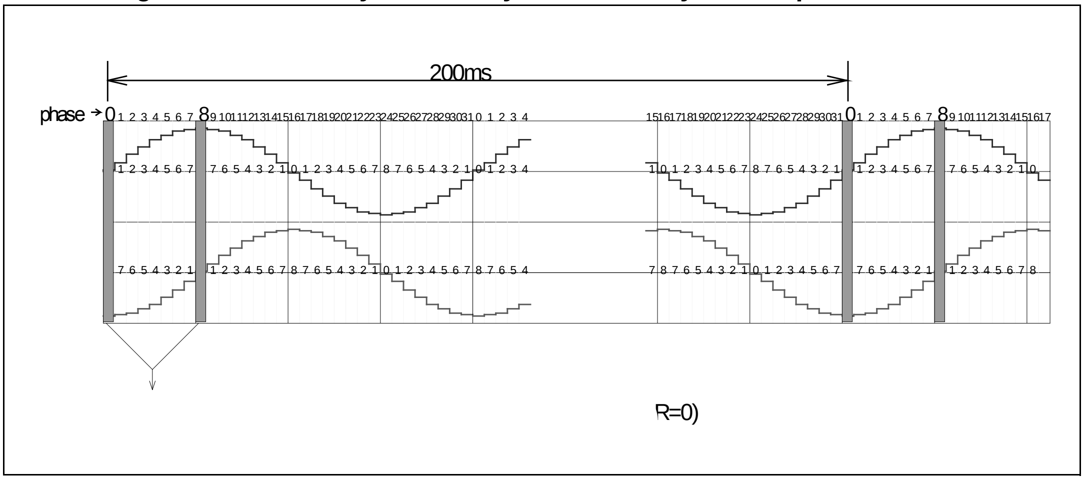
Step Mode	Bridge	DIR=0	DIR=1
Mini step	A	(8, 10,12,14) (24,26,28,30)	(22,20,18,16(1)) (6, 4, 2, 0(1))
	B	(0, 2, 4, 6) (16,18,20,22)	(30,28,26,24(1)) (14,12,10, 8(1))
Micro step	A	(8,9,10,11,12,13,14,15) (24,25,26,27,28,29,30,31)	(23,22,21,20,19,18,17,16(1)) (7, 6, 5, 4, 3, 2, 1, 0(1))
	B	(0, 1, 2, 3, 4, 5, 6, 7) (16,17,18,19,20,21,22,23)	(31,30,29,28,27,26,25,24(1)) (15,14,13,12,11,10, 9, 8(1))

1. Current profile_0 must be greater than 0

2.1 Conclusion

To detect shorted coil in both bridges (A and B) and for all step modes (Full, Half, Mini and Micro), it is necessary to change decay mode to Auto decay, fast decay without delay time at phase counter values of 0 and 8 (or 16 and 24). For the opposite direction, DIR=1 can also use 0 and 8 (or 16 and 24) but the amplitude of current profile_0 must be greater than 0. This configuration is illustrated in *Figure 4*.

Figure 4. Auto decay, fast decay without delay time at phase 0 and 8

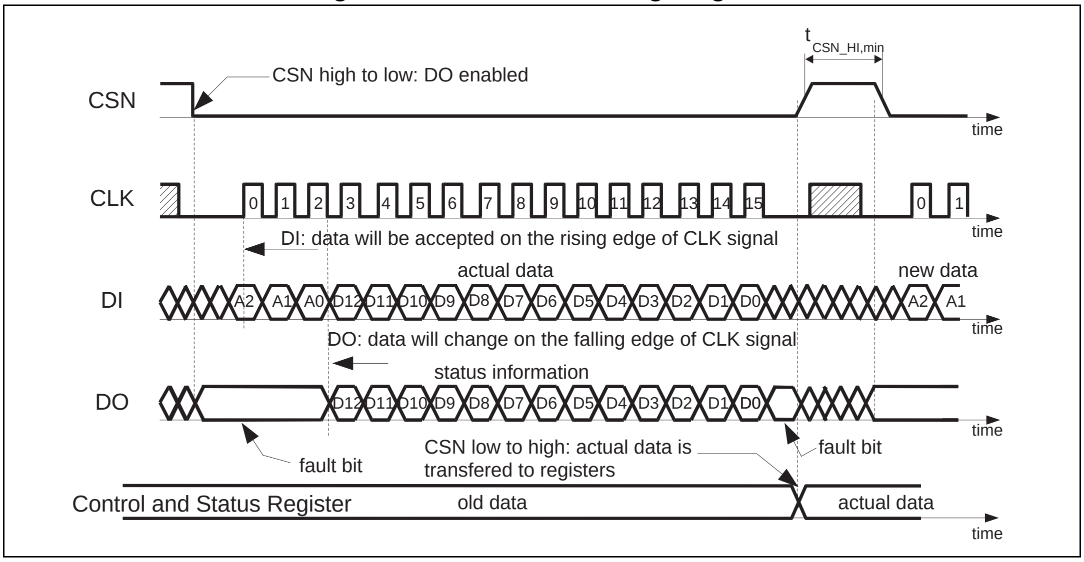


Note: Another possibility is to change the decay mode for Micro, Mini and Half Step mode at phase counter values of 4 and 12 and for Full Step mode at phase counter values of 0 and 8.

3 SPI

3.1 Fault bit

Figure 5. SPI transfer timing diagram



The first three bits of an SPI write frame are the register address. Thus, during this time, it is not clear which register has to be written and read. This time is used at the DO-pin to monitor the or-function of all diagnostic functions.

The register read out is started with the third falling edge of the SPI CLK. The read out is finished 13 falling edges later and during the remaining time, until CSN is set to high, the or-function of all diagnostic functions is monitored again.

Using this method, the failure status of the device can be checked without an SPI communication. CSN is only pulled to low for a short while.

3.2 SPI communication monitoring

SPI communication monitoring is described in the specification.

However, for register 0 the following two points should be considered.

1. During SPI communication, monitoring the STEP-pin must not be used. This could cause the Phase Counter to be modified.
2. When not using the microstepping step mode, not all Current Profile Registers are used. When sending a command to the Control Register 0 for SPI communication monitoring with a Phase Counter value that not used in the selected step mode, the device will correct the Phase Counter value itself. In this case, SPI communication monitoring will fail.

4 Decay modes

During the ON phase the current in the motor coil increases. After an ON phase, an OFF phase follows that always starts with the cross current protection time (tcc).

The cross current protection time is automatically chosen with the slew rate and is typically in the range from 0.5 to 4 µs.

After the cross current protection time, a programmed decay mode follows.

The basic decay modes of the stepper motor driver L9942 are:

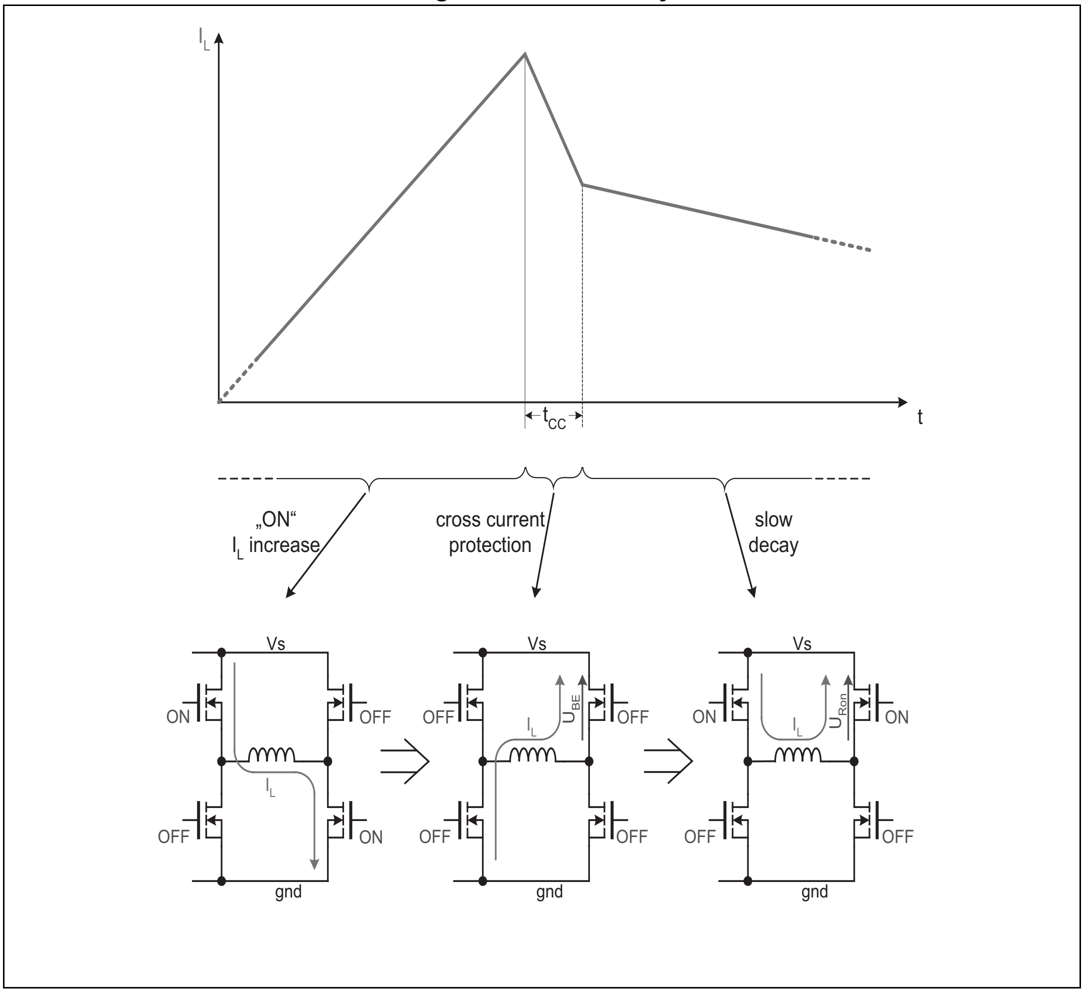
- Slow decay
- Fast decay
- Advanced decay modes, which are combinations of the slow and fast decay modes.

4.1 Slow decay

The slow decay mode realizes a minimum loss of energy in the motor coil. This means the current decrease in the motor coil is “slow”.

Slow decay is illustrated in *Figure 6*.

Figure 6. Slow decay

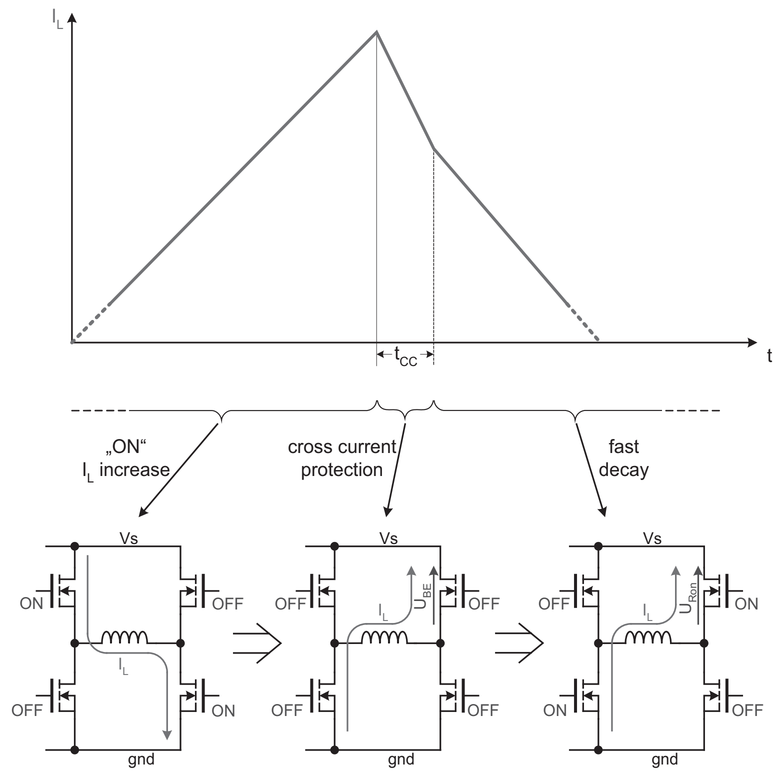


4.2 Fast Decay

The fast decay mode realizes a maximum loss of energy in the motor coil. This means the current decrease in the motor coil is “fast”.

Fast decay is illustrated in *Figure 7*.

Figure 7. Fast decay



4.3 Advanced decay modes

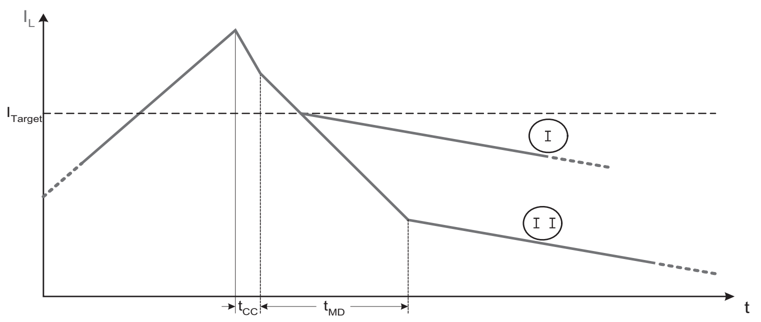
With the stepper motor driver L9942, it is possible to combine the basic decay modes, slow and fast decay.

4.3.1 Mixed decay

From the current point of view, for stepping down it is necessary to reduce the current in the motor coil quickly. Therefore, a mostly slow decay is not useful because there is the danger that the current in the motor coil does not reach the new (lower) current target. With fast decay, the current undershoot may be stronger than necessary; this generates more EMI than necessary.

A better result is obtained by mixing fast decay with slow decay. Mixed decay starts with fast decay and switches to slow decay; the point for switching between the decay modes is programmable. Mixed decay is shown in *Figure 8*.

Figure 8. Mixed decay



- **Mixed decay, fast decay until current undershoot**
  In *Figure 8*, this behavior is shown with graph “I”. Fast decay is driven until the motor coil current has undershot the target current and switches to slow decay until the end of the phase.
- **Mixed decay, fast decay until t_{MD} > 4(8) µs**
  In *Figure 8*, this behavior is shown with graph “II”. The time t_{MD} is started after the cross current protection time tcc is over. After t_{MD} is finished the stepper motor driver switches to slow decay. t_{MD} is programmable to 4µs or 8µs.

4.3.2 Auto decay

If the current in the motor coil is required to increase from step to step, it is sensible to save the current in the motor coil. Therefore, the best decay mode is slow decay (see *Section 4.1*).

If, on the other hand, the current in the motor coil should decrease from step to step, it is sensible to reduce the current in the motor coil in a controlled way, as described in *Section 4.3.1*. Therefore, the best decay mode is mixed decay.

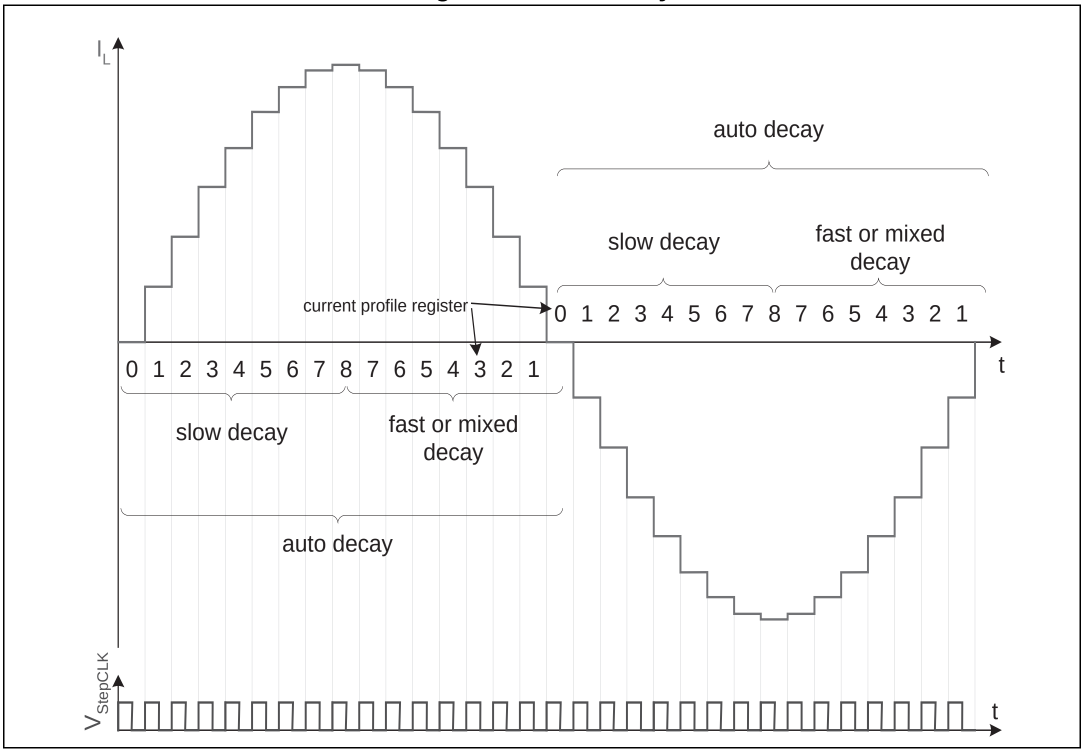
The combination of slow decay for increasing current from step to step and mixed decay for decreasing current from step to step is auto decay. A combination of slow decay and pure fast decay is also possible but this option usually increases the EMI emission.

In *Figure 9*, auto decay is shown for one of the motor coils with micro stepping. For each step, the appropriate current profile register is also shown.

Internally, a pointer moves from a current profile register to the next current profile register with each StepCLK pulse. This start from the register 0 and goes step by step to register 8 and then back to register 0...

When the pointer is going in the direction from register 0 to 8, the L9942 uses slow decay. When the pointer is going from register 8 to 0, mixed or fast decay is selected.

Figure 9. Auto decay



- **Auto decay, fast decay without delay time**
  Slow decay for current profile register going up (0 → 8) plus pure fast decay (see also fast decay in *Figure 7*) for current profile register decreasing (8 ← 0).
- **Auto decay, fast decay until t_{MD} > 4(8) µs:**
  Slow decay for current profile register going up (0 →8) plus mixed decay (see also mixed decay in *Figure 8*, graph “II”) for current profile register decreasing (8 ←0).
- **Auto decay, fast decay until current undershoot**
  Slow decay for current profile register going up (0 ← 8) plus mixed decay (see also mixed decay in *Figure 8*, graph “I”) for current profile register increasing (0 →8).

5 Stall detection

The stall detection function of the L9942 uses the reference drive of a stepper motor system, such as that usually used in the start up phase of a front light levelling system.

5.1 Internal functionality (simplified)

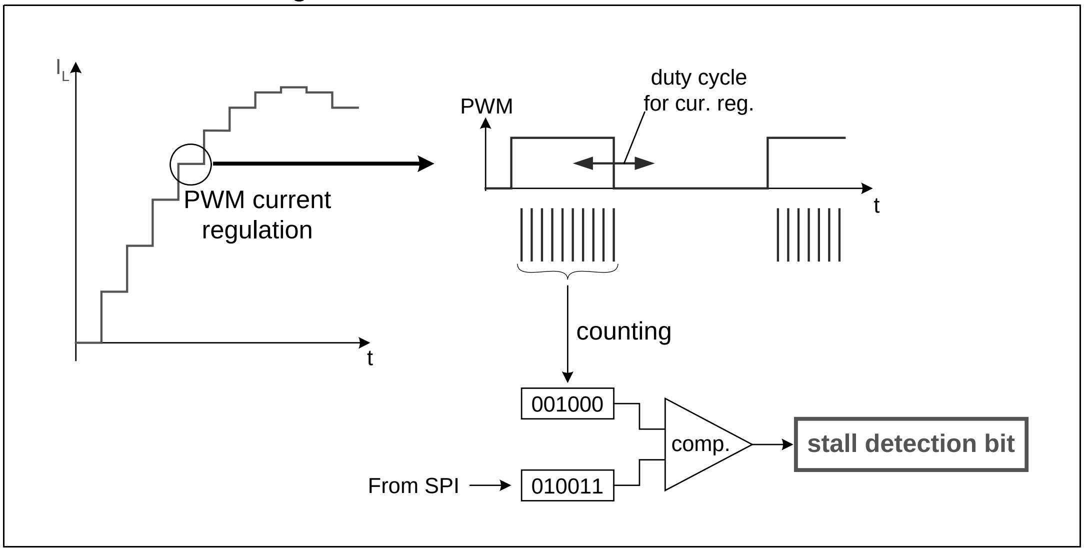
The back EMF of the permanent magnetic rotor of the stepper motor is the effect that is used for the stall detection function.

If the motor is turning “fast”, the back EMF is “high”. Thus, the voltage drop at the motor coils is “low”. Combined with the inductance of the motor coils, it takes a “long” time to reach the target current. Consequently, this means a “long” duty cycle of the pulse width modulation (PWM).

If the motor is stopped mechanically, the back EMF is zero. Thus, the voltage drop at the motor coils is “high”. Combined with the inductance of the motor coils, it takes a “short” time to reach the target current. This means a “short” duty cycle of the PWM.

As is shown in *Figure 10*, an internal counter counts the duty cycle of the current regulation PWM. This value is compared with a value given from the microcontroller via the SPI. If this value is less than the one supplied by the microcontroller, the stall detection bit is set.

Figure 10. Stall detection function overview



5.2 How to determine the stall threshold at bench test

There are four steps to determine the stall threshold.

1. Drive motor in an environment with parameters as in a possible stall situation.
2. Run the motor so that it is turning continually and increase the stall threshold step by step until the stall bit is set. This stall threshold value is called the “high value”.
3. With the same electrical conditions as before, stop the motor mechanically. Decrease the stall threshold from the “high value”. After some steps the stall bit is reset. This stall threshold value is called the “low value”.
4. The stall threshold is the middle value between the “high value” and the “low value”.

6 Duty cycle for current regulation

The duty cycle for current regulation is always switched on for a minimum time and has a maximum time of less than 100%.

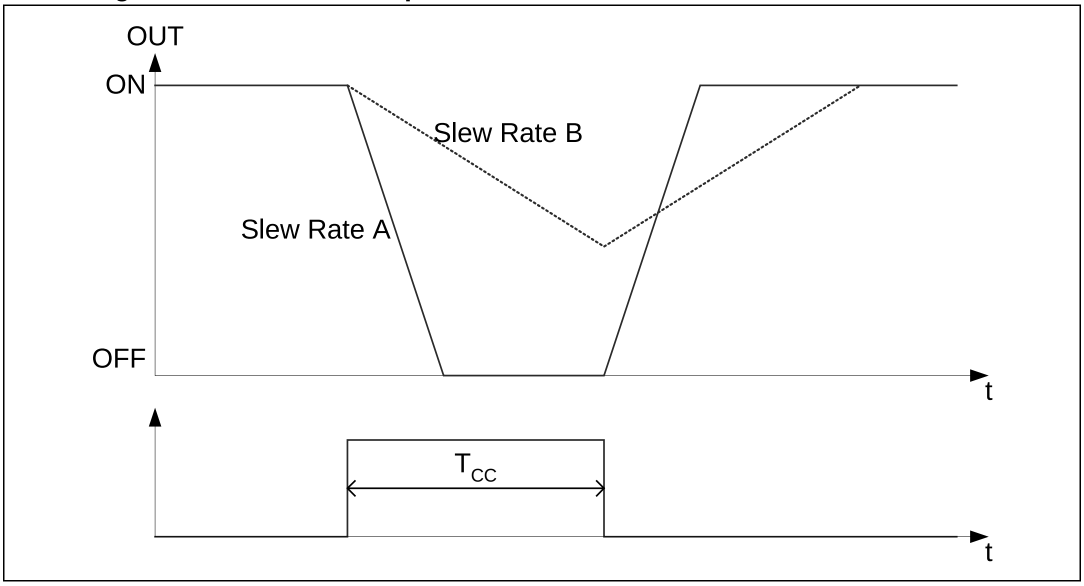
6.1 Minimum duty cycle

The minimum duty cycle is the sum of the “Glitch filter delay time”, the “Slew rate” and the “Cross current protection time”. The “Slew rate” and the “Cross current protection time” are programmed with the same bits.

6.2 Maximum duty cycle

The maximum duty cycle is less then 100%. The negligible off time is related to the “Cross current protection time”. “Cross current protection time” is illustrated in *Figure 11*.

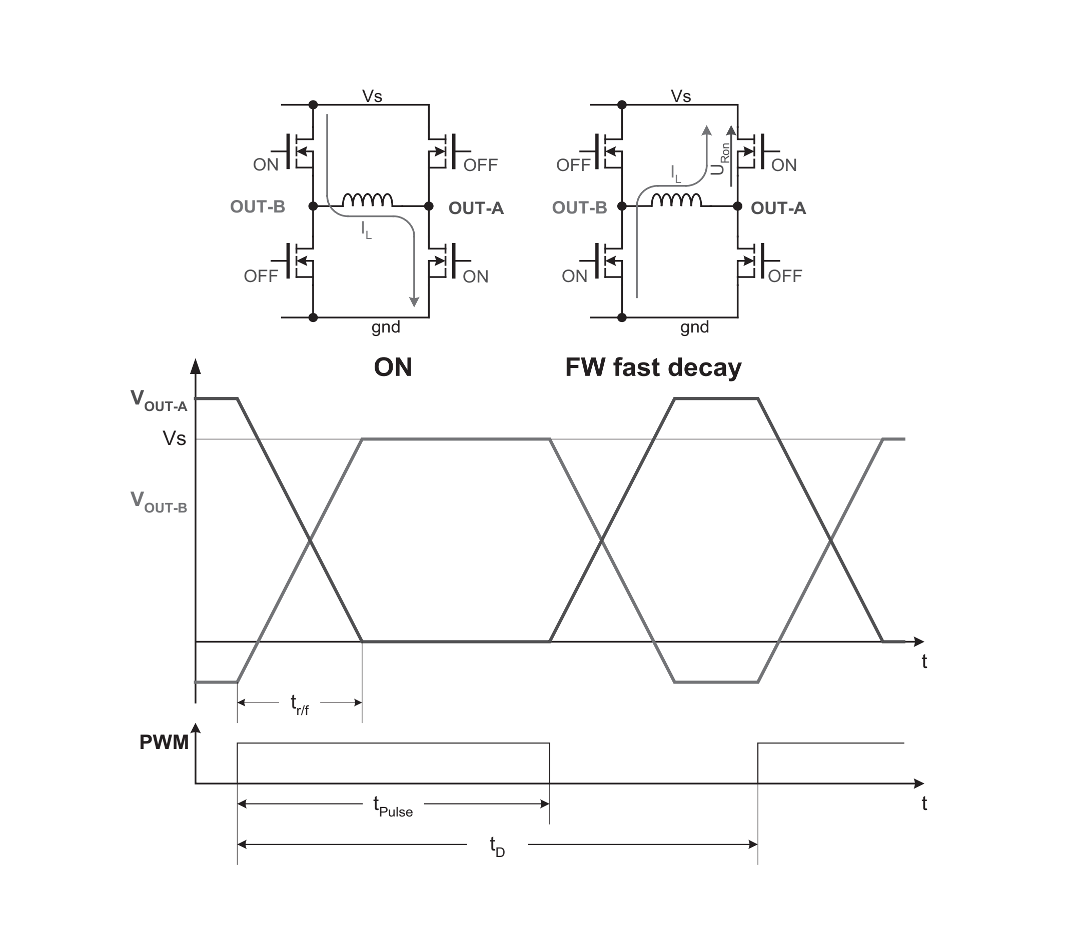
Figure 11. Cross current protection time and slew rate for maximum DC



7 Power dissipation

The calculation of the power dissipation depends upon the selected slew rate and decay mode of the device. In *Figure 12* the set up was selected with a fast decay.

Figure 12. Current flow and voltage drop during fast decay



For a rough calculation of the power dissipation, three different phases are selected:

1. Static ON
2. Static free wheeling (FW), fast decay
3. Dynamic on and off with slew rate.

7.1 Static ON

Only the RDS,on of the high and low side switches are used for generating power dissipation.

7.2 Static freewheeling

Only the RDS,on of the high and low side switches are used for free wheeling and generating power dissipation.

7.3 Dynamic slew rate power dissipation

During the H-bridge switching, the voltage and the current chang in a triangular form with the defined slew rate.

7.4 Power dissipation for one PWM phase

The temporary power dissipations, explained above, are summed for the complete PWM phase.

$$P = P_{ON} \cdot \left(\frac{t_{Pulse} - t_r/f}{t_D}\right) + P_{FW} \cdot \left(\frac{t_D - t_{Pulse} - t_r/f}{t_D}\right) + 2 \cdot P_{SR} \cdot \left(\frac{2 \cdot t_r/f}{t_D}\right)$$

$$P = P_{ON} \cdot \left(\frac{t_D - 2 \cdot t_r/f}{t_D}\right) + 2 \cdot \left[P_{SR} \cdot \left(2 \cdot \frac{t_r/f}{t_D}\right)\right]$$

$$P = 2 \cdot R_{DSON} \cdot I^2 \cdot \left(\frac{t_D - 2 \cdot t_r/f}{t_D}\right) + 2 \cdot U \cdot I \cdot \left(\frac{t_r/f}{t_D}\right)$$

8 PCB footprint proposal

Figure 13. Power SSO24 solder mask layout (all values in mm)

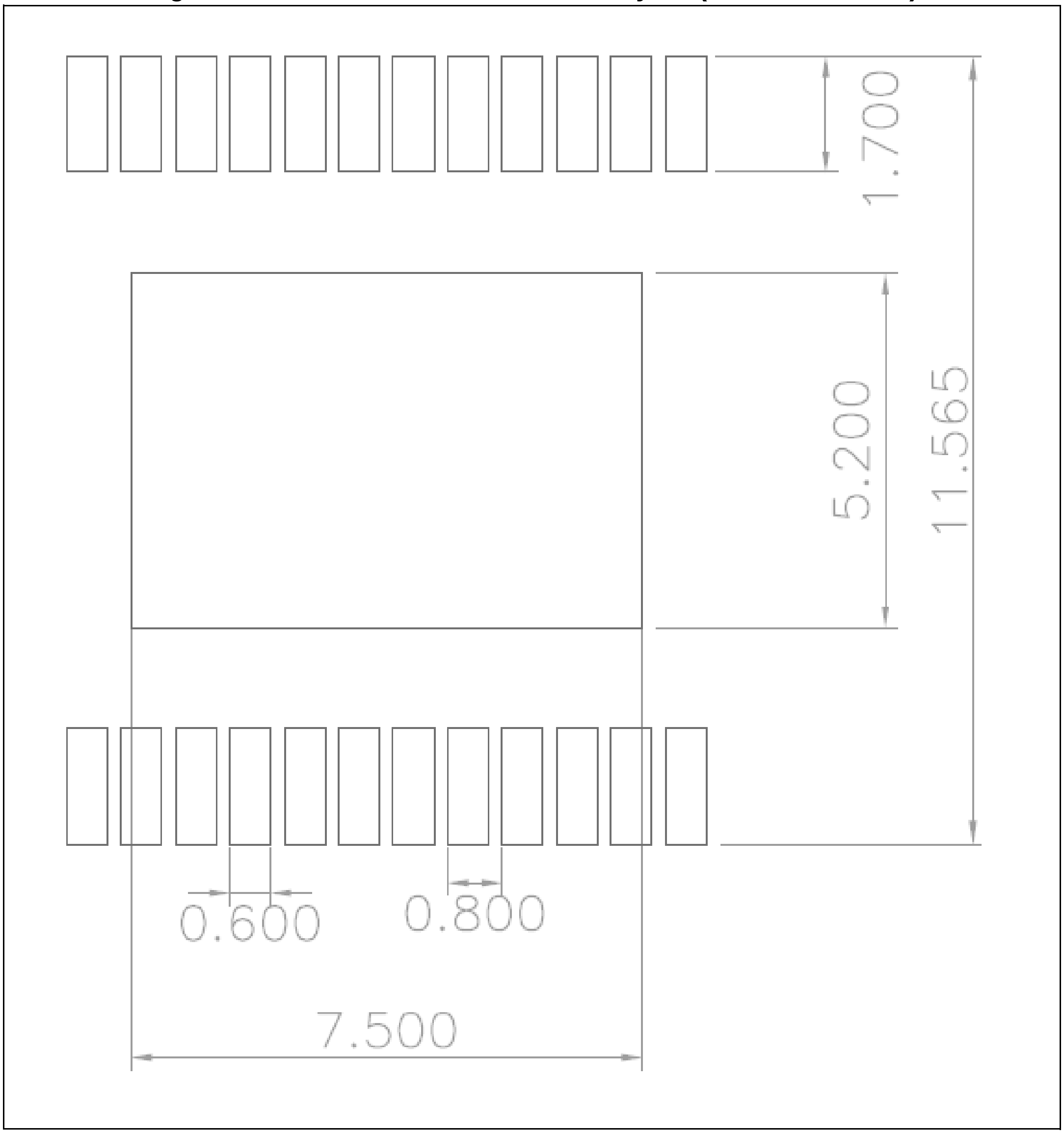
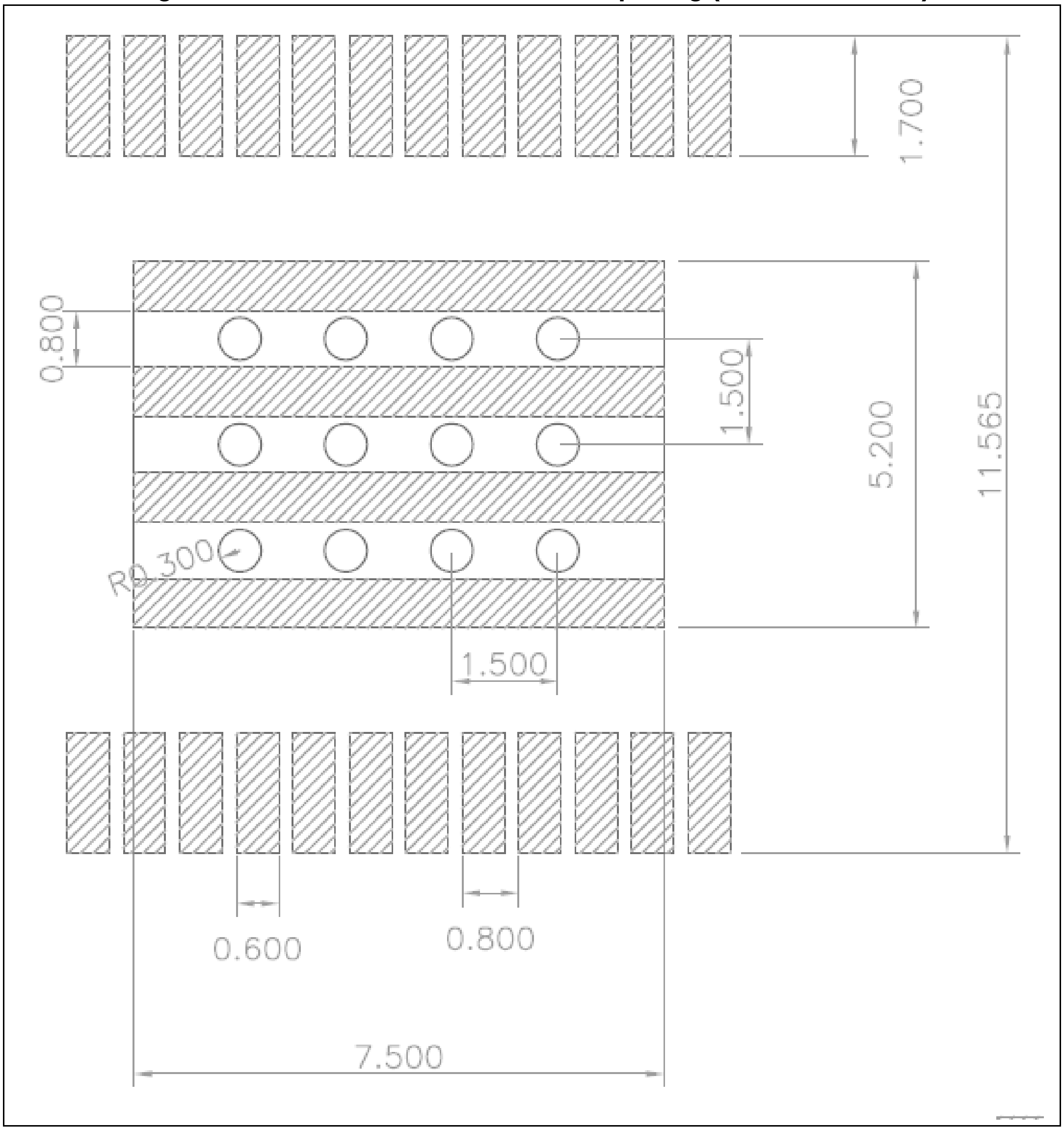


Figure 14. Power SSO24 solder mask opening (all values in mm)



9 Revision history

Table 2. Document revision history

Date	Revision	Changes
2-Nov-2007	1	Initial release.
22-Sep-2013	2	Updated Disclaimer.
05-Dec-2013	3	Updated equation into *Section 7.4: Power dissipation for one PWM phase*