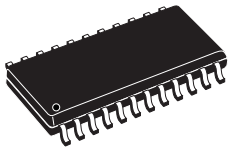
L9524C

Glow plug system control IC

Features

- Quad gate driver for external N-channel Power MOSFETs in high-side configuration:
  - Gates driven by PWM output signal
  - Adjustable gate charge/discharge currents
  - Limited gate-to-source voltages
  - Negative clamping for inductive loads
  - Advanced run-off control
  - Regulation of the power through the glow plugs
- Control output for external relay driver
- Battery-voltage-compatible two-wire interface
- Supply voltage monitoring with shutdown
- Battery voltage monitoring with shutdown
- Junction temperature monitoring with shutdown
- Monitoring of currents through the glow plugs with shutdown at overcurrent (adjustable threshold)
- Monitoring of external switches
- Charge pump voltage monitoring with shutdown
- Active clamping during load dump



SO24

Description

The L9524C is a control IC for up to six glow plugs of diesel engines. The glow plugs are switched by up to four external PWM-controlled N-channel Power MOSFETs or a single relay in high-side configuration.

Supply voltage, battery voltage, junction temperature, switches, currents through the glow plugs, and charge pump voltage are monitored.

A two-wire interface is used to communicate with the diesel engine management system.

Table 1. Device summary

Order code	Package	Packing
L9524C	SO24	Tube
L9524C-TR	SO24	Tape and reel

Contents

1 Block diagram 5

2 Pins description 6

3 Electrical specifications 7

3.1 Absolute maximum ratings 7

3.2 Thermal data 7

3.3 Electrical characteristics 8

4 Functional description 12

4.1 Operating modes 12

4.2 Supply 13

4.3 Control input 14

4.4 Diagnostic output 15

4.5 Current monitoring 17

4.6 Switch monitoring 18

4.7 Thermal shutdown 18

4.8 Gate drivers 18

4.9 Relay output 19

4.10 Gate charge/discharge current variation 19

4.11 Overcurrent threshold variation 19

4.12 Advanced run-off control 20

4.13 Output timing 20

4.14 Power regulation 21

5 Application diagrams 22

6 Package information 25

7 Revision history 26

List of tables

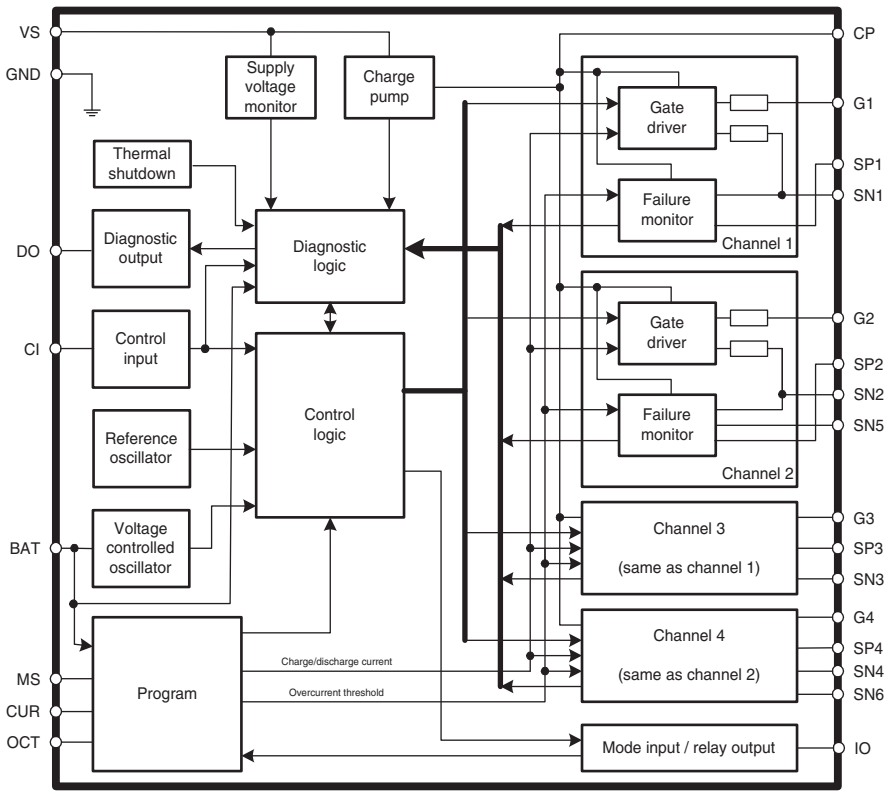
Table 1. Device summary . . . 1
Table 2. Pins description . . . 6
Table 3. Absolute maximum ratings . . . 7
Table 4. Thermal data . . . 7
Table 5. Electrical characteristics . . . 8
Table 6. Mode . . . 12
Table 7. Go / no-go protocol description . . . 16
Table 8. Failure register description . . . 16
Table 9. Sense input pin connection . . . 17
Table 10. Document revision history . . . 26

List of figures

Figure 1. Block diagram . . . 5
Figure 2. Pin connection (top view) . . . 6
Figure 3. Shunt sense versus transistor sense . . . 13
Figure 4. Control input signal in transistor mode (modes 3 to 6) . . . 14
Figure 5. Permanent switch on of glow plugs at first falling edge in transistor mode (modes 3 to 6) 14
Figure 6. Control input signal in mode 2 for permanent switch on . . . 15
Figure 7. Serial diagnostic interface protocol . . . 17
Figure 8. Timing diagram of advanced run-off control . . . 20
Figure 9. Output timing . . . 20
Figure 10. Mode 1: relay mode, go/no-go diagnostic interface protocol . . . 22
Figure 11. Mode 2: relay mode, serial diagnostic interface protocol . . . 22
Figure 12. Mode 3: transistor mode, shunt sense, no power regulation . . . 23
Figure 13. Mode 4: transistor mode, shunt sense, power regulation . . . 23
Figure 14. Mode 5: transistor mode, transistor sense, no power regulation . . . 24
Figure 15. Mode 6: transistor mode, transistor sense, power regulation . . . 24
Figure 16. SO24 mechanical data and package dimensions . . . 25

1 Block diagram

Figure 1. Block diagram



2 Pins description

Figure 2. Pin connection (top view)

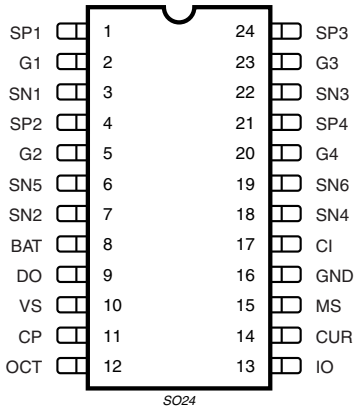


Table 2. Pins description

Pins #	Name	Function
1	SP1	Positive sense input, glow plug 1
2	G1	Driver output for external high-side power MOSFET, transistor 1
3	SN1	Negative sense input, glow plug 1
4	SP2	Positive sense input, glow plugs 2 and 5
5	G2	Driver output for external high-side power MOSFET, transistor 2
6	SN5	Negative sense input, glow plug 5
7	SN2	Negative sense input, glow plug 2
8	BAT	Battery voltage input
9	DO	Diagnostic output
10	VS	Supply voltage input
11	CP	Charge pump output
12	OCT	Overcurrent threshold setting
13	IO	Transistor mode: input for selection of power regulation feature Relay mode: output to control external relay driver
14	CUR	Power MOSFET gate charge/discharge current setting
15	MS	Mode selection input: transistor modes (transistor sense / shunt sense) / relay mode
16	GND	Ground pin
17	CI	Control input
18	SN4	Negative sense input, glow plug 4
19	SN6	Negative sense input, glow plug 6
20	G4	Driver output for external high-side power MOSFET, transistor 4
21	SP4	Positive sense input, glow plugs 4 and 6
22	SN3	Negative sense input, glow plug 3
23	G3	Driver output for external high-side power MOSFET, transistor 3
24	SP3	Positive sense input, glow plug 3

3 Electrical specifications

3.1 Absolute maximum ratings

Table 3. Absolute maximum ratings

Symbol	Parameter	Value	Unit
V_{VS}	Supply voltage range	-0.3 to 45	V
$\|dV_{VS}/dt\|$	Supply voltage slope	10	V/µs
V_{CP}	Charge pump voltage range	-0.3 to 45	V
V_{BAT}, V_{CI}, V_{SP1-4}, V_{SN1-6}	Input pin voltage range (BAT, CI, SP1-4, SN1-6)	-16 to 45	V
V_{OCT}, V_{CUR}, V_{MS}, V_{IO}	Input pin voltage range (OCT, CUR, MS, IO)	-0.3 to 7	V
V_{DO}, V_{G1-4}	Output pin voltage range (DO, G1-4)	-16 to 45	V

Warning: The device may become damaged if using externally applied voltages or currents exceeding these limits!

All the pin of the IC are protected against ESD. the verification is performed according to: AEC Q100-002 (HBM) and AEC Q100-011 (CDM).

3.2 Thermal data

Table 4. Thermal data

Symbol	Parameter	Value	Unit
T_J	Operating junction temperature	-40 to 125	°C
T_{JSD}	Junction temperature thermal shutdown threshold	125 to 150	°C

3.3 Electrical characteristics

5V ≤ V_{VS};V_{BAT} ≤ 18V, -40°C ≤ T_J ≤ 125°C, unless otherwise specified. The voltages are referred to GND and currents are assumed positive, when current flows into the pin.

Table 5. Electrical characteristics

Item	Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
Supply (VS)							
1.1	I_{VS}	Supply current		1	5	20	mA
			V_S = 12V	1		10	mA
1.2	$V_{VS\ uv}$	Undervoltage threshold		4		5	V
1.3	$V_{VS\ uvh}$	Undervoltage threshold hysteresis (1)		100		400	mV
1.4	$V_{VS\ ol}$	Open-load detection threshold		5.5		7.2	V
1.5	$V_{VS\ ov}$	Overvoltage threshold		18		22	V
1.6	$V_{VS\ ovh}$	Overvoltage threshold hysteresis (1)		0.4		1.6	V
1.7	$V_{VS\ ld}$	Load dump threshold		28		35	V
1.8	$t_{VS\ fil}$	Filter time (2)		1		2	ms
1.9	$t_{VS\ ld}$	Load dump delay time (1)			10		µs
Supply (BAT)							
2.1	$I_{BAT\ leak}$	Leakage current	V_{VS} ≤ 3V 0V ≤ V_{BAT} ≤ 12V	0		5	µA
2.2	R_{BAT}	Internal pull-down resistance	-40°C	25	43	150	kΩ
			30°C	25	65	150	
			125°C	25	106	150	
2.3	$V_{BAT\ uv}$	Battery undervoltage threshold	V_{MS} > $V_{MS\ tr}$ (transistor mode)	1		2	V
2.4	$t_{BAT\ fil}$	Filter time (2)		300		760	µs
Charge pump (CP)							
3.1	V_{CP}	Charge pump voltage	I_{CP} = -100µA	V_{VS} +5V		V_{VS} +18V	
3.2	I_{CP}	Charging current	V_{CP} = V_{VS} + 5V	-1500		-100	µA
3.3	$V_{CP\ uv}$	Charge pump undervoltage threshold		V_{VS} +3.5V		V_{VS} +5V	
3.4	f_{CP}	Charge pump frequency (1)		0.6		7	MHz
3.5	$t_{CP\ fil}$	Filter time (2)		400		950	µs

Table 5. Electrical characteristics (continued)

Item	Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
Control input (CI)							
4.1	$V_{CI\ off}$	Input “off” level		0.6 · V_{VS}			
4.2	$V_{CI\ on}$	Input “on” level				0.4 · V_{VS}	
4.3	$V_{CI\ h}$	Off-to-on hysteresis (1)		0.03 · V_{VS}	0.04 · V_{VS}	0.05 · V_{VS}	
4.4	$V_{CI\ to}$	Input “timeout” threshold		1		1.6	V
4.5	R_{CI}	Internal pull-up resistance	$V_{CI} \le V_{VS}$; -40°C	20	35	120	kΩ
			$V_{CI} \le V_{VS}$; 30°C	20	53	120	
			$V_{CI} \le V_{VS}$; 125°C	20	87	120	
4.6	$t_{CI\ fil}$	Filter time (2)		0.5		1	ms
4.7	$t_{CI\ to}$	PWM time-out (2)		50		100	ms
Diagnostic output (DO)							
5.1	V_{DOL}	Output low voltage	$V_{VS} \ge 4.5V$; $I_{DO} \le 5mA$	0.3		1.5	V
5.2	R_{DO}	Internal pull-up resistance	$V_{DO} \le V_{VS}$; -40°C	20	30	120	kΩ
			$V_{DO} \le V_{VS}$; 30°C	20	45	120	
			$V_{DO} \le V_{VS}$; 125°C	20	74	120	
5.3	$I_{DO\ max}$	Current limitation		5		20	mA
Monitoring of currents through glow plugs (SP1-SN1, SP2-SN2, SP3-SN3, SP4-SN4, SP2-SN5, SP4-SN6)							
6.1	ΔV_{OL}	Open-load threshold	$6V \le V_{SPX}; V_{SNX} \le V_{VS} + 3V$	6.7		14.7	mV
6.2	$\Delta V_{OC\ 0}$	Overcurrent threshold	$1.5V \le V_{SPX}; V_{SNX} \le V_{VS} + 3V$ $V_{MS} < V_{MS\ tc}$ (shunt sense) OCT pin open	150		185	mV
			$1.5V \le V_{SPX}; V_{SNX} \le V_{VS} + 3V$ $V_{MS} < V_{MS\ tc}$ (shunt sense) $0V \le V_{OCT} \le V_{CUR}$	V_{OCT} · 0.385		V_{OCT} · 0.445	
			$1.5V \le V_{SPX}; V_{SNX} \le V_{VS} + 3V$ $V_{MS} > V_{MS\ tc}$ (transistor sense) ϑ = -40°C; OCT pin open	150		290	mV
			$1.5V \le V_{SPX}; V_{SNX} \le V_{VS} + 3V$ $V_{MS} > V_{MS\ tc}$ (transistor sense) ϑ = -40°C; $0V \le V_{OCT} \le V_{CUR}$	V_{OCT} · 0.345		V_{OCT} · 0.485	
6.3	TC_{OC}	Overcurrent threshold temperature coefficient	$V_{MS} < V_{MS\ tc}$ (shunt sense) 1)		0		K^{-1}
			$V_{MS} > V_{MS\ tc}$ (transistor sense) OCT pin open	0.008		0.012	K^{-1}
6.4	$t_{OL\ fil}$	Open-load filter time (2)	$V_{MS} > V_{MS\ tr}$ (transistor mode)	1		2	ms

Table 5. Electrical characteristics (continued)

Item	Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
6.5	$t_{OC\ fil}$	Overcurrent filter time (2)		400		950	µs
Monitoring of external switches (SN1, SN2, SN3, SN4)							
7.1	V_{SD}	Switch defect threshold		V_{VS} · 0.4		V_{VS} · 0.6	
7.2	$t_{SD\ fil}$	Switch defect filter time (2)		1		2	ms
Gate driver outputs (G1, G2, G3, G4)							
8.1	$V_{G\ off}$	Gate off voltage	$I_{GX} \leq 100\mu A$	V_{SNX}		V_{SNX} +0.7V	
8.2	$V_{G\ on}$	Gate on voltage	$V_{SNX} = V_{VS}$	V_{VS} +5V		V_{VS} +10V	
8.3	$V_{G\ cl}$	Gate clamping voltage	V_{SNX} = -20V	-18		-16	V
8.4	$I_{G\ off}$	Gate discharge current	I_{CUR} = -125µA	270		540	µA
8.5	$I_{G\ on}$	Gate charge current	I_{CUR} = -125µA	270		540	µA
8.6	Slope	Gate charge- discharge-current I_G/I_{CUR}	-250µA ≤ I_{CUR} ≤ -70µA	2.33		4.33	
8.7	R_G	Output resistance (1)			1		kΩ
8.8	$\Delta t_{G\ on}$	Jitter of output on time		-300		300	µs
Mode input / relay output (IO)							
9.1	$V_{IO\ on}$	Output on voltage	$I_{IO} \geq -100\mu A$	3		6	V
9.2	R_{IO}	Output resistance	$I_{IO} \geq$ -1mA	100		500	W
9.3	I_{IO}	Input pull-down current	$V_{IO} \geq$ 1V	25		100	µA
			V_{VS} = 0V	50		500	µA
9.4	$I_{IO\ max}$	Current limitation		-25		-5	mA
9.5	$V_{IO\ pr}$	Power regulation threshold		1		2	V
9.6	$t_{IO\ sup}$	Pulse suppress time (2)		2.5		5	ms
Positive sense inputs (SP1, SP2, SP3, SP4)							
10.1	$I_{SP\ leak}$	Leakage current	$V_{VS} \leq$ 3V	0		5	µA
10.2	I_{SP}	Input pull-down current	$V_{SNX} = V_{SPX} \geq$ 6V	15		780	µA
10.3	R_{SP1-4}	Pull-down resistor	6V ≤ $V_{SNX} = V_{SPX} \leq$ 20V -40°C	40	100	270	kΩ
			35°C	40	150	270	
			125°C	40	220	270	
Negative sense inputs (SN1, SN2, SN3, SN4, SN5, SN6)							
11.1	I_{SN}	Input pull-down current	$V_{SNX} = V_{SPX} \geq$ 6V	15		780	µA

Table 5. Electrical characteristics (continued)

Item	Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
11.2	R_{SN1-6}	Pull down resistor	$6V \le V_{SNX} = V_{SPX} \le 20V$ -40°C	40	100	270	kΩ
			35°C	40	150	270	
			125°C	40	220	270	
Overcurrent threshold setting (OCT)							
12.1	I_{OCT}	Input pull-up current	$V_{VS} \ge 6V$ $V_{OCT} = 3.5V$	-40		-10	µA
Power MOSFET gate charge/discharge current setting (CUR)							
13.1	V_{CUR}	Output voltage	$I_{CUR} \ge -150µA$	2.35	2.5	2.65	V
13.2	$I_{CUR\ max}$	Current limitation	$V_{CUR} \le 2V$	-500		-250	µA
Input pin for mode selection (MS)							
14.1	I_{MS}	Pull-up current	$V_{MS} = 3V$	-60		-15	µA
14.2	$V_{MS\ tr}$	Transistor mode threshold		1		2	V
14.3	$V_{MS\ tc}$	Temperature compensation threshold	$V_{VS} \ge 6V$	3		4	V
Output timing							
15.1	t_{del}	Delay time (2)		2.5		5	ms
15.2	t_{gap}	Gap between channels (2)		50		250	µs
15.3	t_{sup}	Failure suppress time (2)		400		950	µs
Power regulation							
16.1	ΔV_{RMS}	Accuracy	$8V \le V_{BAT} \le 16V$ $30ms \le T_{CI} \le 33ms$ $t_{CI\ on}/T_{CI} \ge 20\%$ < 70°C	-1.5		1.5%	% . V_{RMSref}
			> 70°C	-2		2	

1. not tested, guaranteed by design
2. time constants created digitally, verified by scan path test

4 Functional description

4.1 Operating modes

The L9524C can operate in a total of 6 modes. The selection is done by short-circuiting the appropriate pins and voltages as shown in the following table:

Table 6. Mode

Mode	Description	MS pin	BAT pin	IO pin	CI pin
1	relay mode, go/no-go diagnostic interface protocol	ground	ground	output	statical signal
2	relay mode, serial diagnostic interface protocol	ground	battery	output	PWM signal
3	transistor mode, shunt sense, no power regulation	CUR pin	battery	CUR pin	PWM signal
4	transistor mode, shunt sense, power regulation	CUR pin	battery	ground	PWM signal
5	transistor mode, transistor sense, no power regulation	open	battery	CUR pin	PWM signal
6	transistor mode, transistor sense, power regulation	open	battery	ground	PWM signal

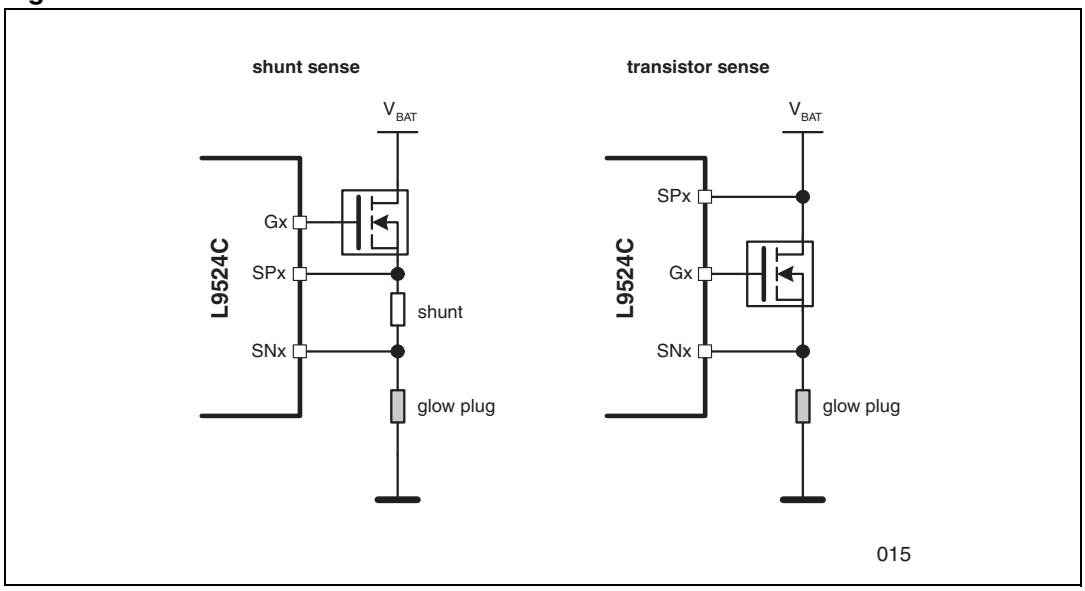
Modes 1 and 2 are for relay usage (referred to as “relay mode”) and modes 3 to 6 for transistors usage (referred to as “transistor mode”).

In relay mode the protocol of the diagnostic interface (DO pin) can be selected from go/no-go protocol and serial protocol (see section “Diagnostic output” for protocol description).

In transistor mode the protocol of the diagnostic interface is the serial protocol. It can be distinguished between using shunts for monitoring the current through the glow plugs (referred to as “shunt sense”) or using the $R_{DS(on)}$ of the power MOSFET’s themselves (referred to as “transistor sense”). In shunt sense mode the resistance of the shunt is assumed to be constant with respect to the temperature while in transistor sense mode the $R_{DS(on)}$ of the power MOSFET’s is assumed to vary with respect to the temperature and therefore overcurrent monitoring is adjusted appropriately.

In transistor mode there are two possibilities to control the output timing. In modes 3 and 5 the timing of the PWM control input signal determines the timing of the PWM signals applied to the external power MOSFET’s (“no power regulation”). In modes 4 and 6 the timing of the PWM control input signal determines the power through the glow plugs (“power regulation”) and the timing of the PWM signals applied to the external power MOSFET’s is adjusted depending on the battery voltage (see section “Power regulation”).

Figure 3. Shunt sense versus transistor sense



4.2 Supply

The main supply pin of the L9524C is the VS pin. The voltage applied to it (V_{VS}) is monitored

- to switch off all glow plugs if it is less than $V_{VS\ uv}$ for at least $t_{VS\ fil}$ (“under voltage failure”),
- to switch off all glow plugs if it is greater than $V_{VS\ ov}$ for at least $t_{VS\ fil}$ (“over voltage failure”),
- to switch on all glow plugs if it is greater than $V_{VS\ ld}$ for at least $t_{VS\ ld}$ (“active clamping during load dump”),
- to ignore open-load failures if it is less than $V_{VS\ ol}$.

Note: The glow plugs are switched on again if the corresponding switch-on condition disappears, except if the glow plugs are switched on because of load dump. Then they remain switched on until V_{VS} is less than $V_{VS\ ov}$ for at least $t_{VS\ fil}$.

In modes 2 to 6, the L9524C is additionally supplied by the BAT pin. This auxiliary supply ensures that the external power MOSFET’s are switched off if no main supply voltage is available at the VS pin.

The BAT pin is additionally used to sense the battery voltage V_{BAT} for power regulation in modes 4 and 6 (see section “Power regulation”) and for detecting “battery under voltage failure” (fuse between battery and module is defect) if V_{BAT} is less than $V_{BAT\ uv}$ for at least $t_{BAT\ fil}$ in modes 2 to 6.

An additional supply voltage higher than the main supply voltage is generated by an internal charge pump which charges an external storage capacitor connected to the CP pin. This capacitor mainly supplies the gates of the external n-channel power MOSFET’s. The charge pump voltage V_{CP} is monitored and the glow plugs are switched off if it is less than $V_{CP\ uv}$ for at least $t_{CP\ fil}$ (“charge pump under voltage”). Afterwards, the glow plugs remain switched off even if the charge pump voltage becomes greater than $V_{CP\ uv}$ until they are explicitly switched on again by the CI (control input) pin.

4.3 Control input

The control input (CI) pin is resistively pulled up R_{CI} to the supply voltage V_{VS} such that $V_{CI}=V_{CI\ off}$ and the glow plugs are switched off by default. The L9524C is controlled by transitions of V_{CI} from $V_{CI\ off}$ to $V_{CI\ on}$ (falling edge) and vice versa (rising edge). Voltage level changes of V_{CI} which last shorter than $t_{CI\ fil}$ are ignored.

In transistor mode (modes 3 to 6) the L9524C expects a PWM signal at the CI pin. Each falling edge starts measuring its on time $t_{CI\ on}$ (time until next rising edge, i.e. length of this low pulse) and its period T_{CI} (time until next falling edge). The end of a pulse group is detected if no falling edge occurs for a time greater than $t_{CI\ to}$ and the glow plugs are switched off. Therefore, it is not possible to switch on the glow plugs permanently with one exception: if the low voltage level of the first falling edge is greater than $V_{CI\ to}$ the glow plugs remain switched on as long as this low pulse lasts.

Figure 4. Control input signal in transistor mode (modes 3 to 6)

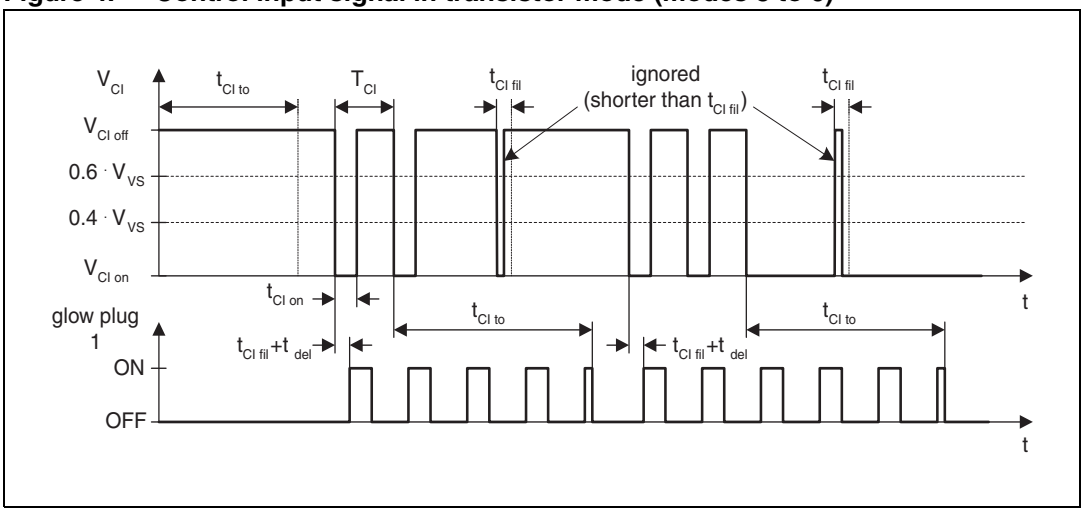
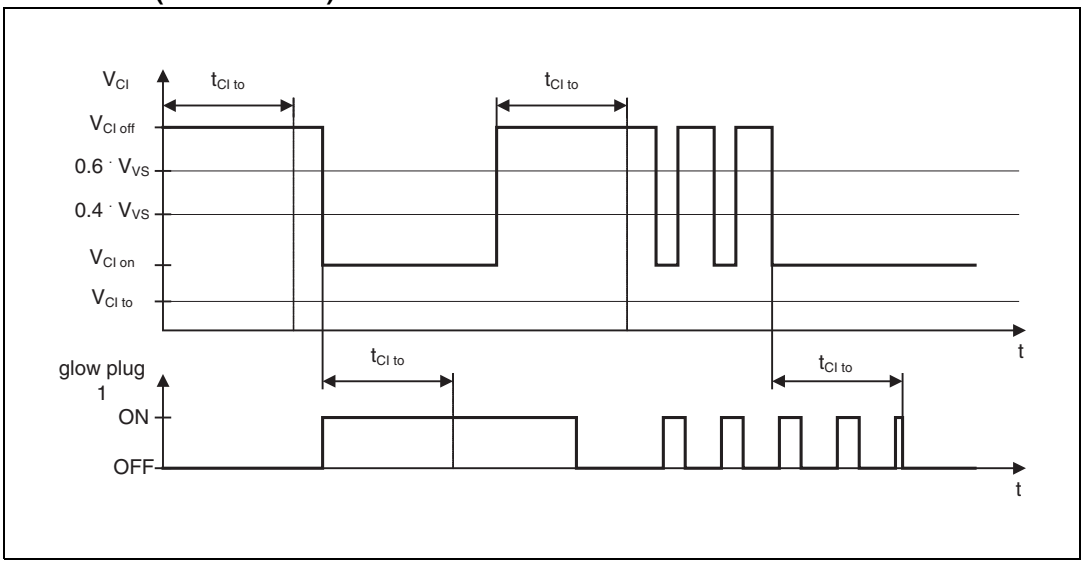
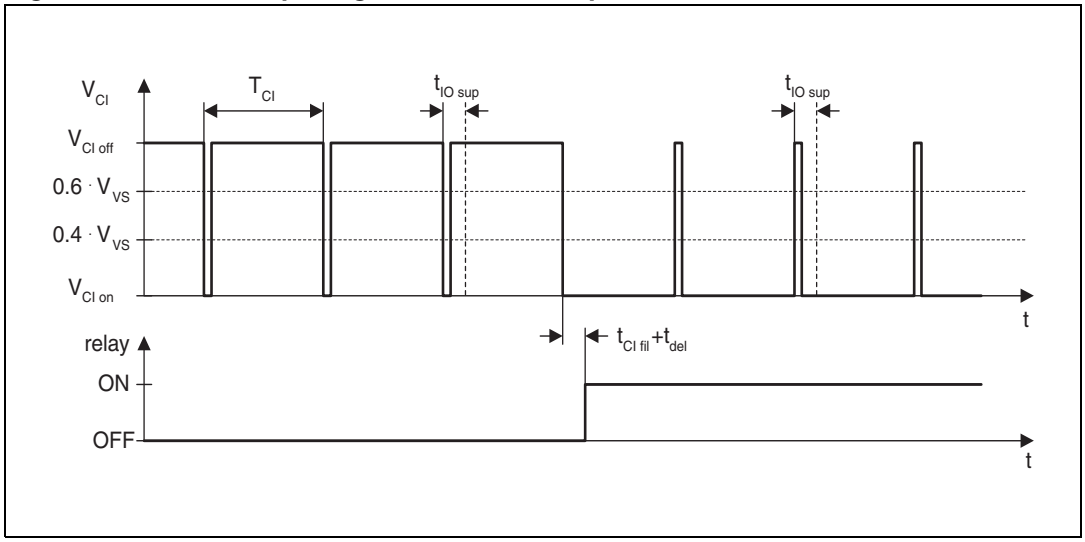


Figure 5. Permanent switch on of glow plugs at first falling edge in transistor mode (modes 3 to 6)



Though in mode 2 (relay mode, serial diagnostic interface protocol) the relay should be switched permanently the L9524C also expects a PWM signal at the CI pin since the serial diagnostic interface protocol is synchronized by falling edges of the CI signal (see section “Diagnostic output”). The relay then is switched on permanently if the off time (time between rising and falling edge) of the PWM signal is less than $t_{IO\ sup}$ since the relay output suppresses pulses shorter than $t_{IO\ sup}$ (see section “Relay output”). For the same reason the relay is switched off permanently if the on time (time between falling and rising edge) of the PWM signal is less than $t_{IO\ sup}$. In all other cases the relay is switched according to the PWM signal at the CI pin.

Figure 6. Control input signal in mode 2 for permanent switch on



In mode 1 (relay mode, go/no-go diagnostic interface protocol) no edges are necessary for the go/no-go protocol. Therefore the relay is switched on if $V_{CI} = V_{CI\ on}$ and it is switched off if $V_{CI} = V_{CI\ off}$.

4.4 Diagnostic output

The diagnostic output stage of the L9524C (DO pin) consists of a current-limited low-side switch and a pull-up resistor R_{DO} to the VS pin. The voltage level of a logical low signal V_{DOL} is given by the drop across the low-side switch and the voltage level of a logical high signal is equal to V_{VS}.

The L9524C is able to detect the following failures (see sections “Supply”, “Current monitoring”, and “Switch monitoring”):

- open-load (6 glow plugs),
- overcurrent (6 glow plugs, stored until power-down),
- any switch is defect (4 switches),
- supply voltage (V_{VS}) is too low (“under voltage”),
- supply voltage (V_{VS}) is too high (“over voltage”),
- junction temperature (T_J) is too high,
- charge pump voltage (V_{CP}) is too low (“charge pump under voltage”), and
- battery voltage (V_{BAT}) is too low (“battery under voltage”).

In order to report the occurrence of any of the above-listed failures to the diesel engine management system the L9524C provides two protocols: go/no-go protocol for mode 1 and serial protocol for modes 2 to 6.

The go/no-go protocol is only able to report if any of the above-listed failures occurred. This is done according to the following table:

Table 7. Go / no-go protocol description

V_{CI}	V_{DO} at “no failure”	V_{DO} at “any failure”
$V_{CI\ off}$	V_{DOL}	V_{VS}
$V_{CI\ on}$	V_{VS}	V_{DOL}

Note: overcurrent failures are stored until power-down.

The serial protocol is able to report different kinds of failures and to assign them to the corresponding glow plugs. Therefore, occurring failures are written into an internal 8-bit failure register:

Table 8. Failure register description

Bit	Meaning of high state
1	Open-load or overcurrent (1) failure at glow plug 1
2	Open-load or overcurrent (1) failure at glow plug 2
3	Open-load or overcurrent (1) failure at glow plug 3
4	Open-load or overcurrent (1) failure at glow plug 4
5	Open-load or overcurrent (1) failure at glow plug 5
6	Open-load or overcurrent (1) failure at glow plug 6
7	Overcurrent failure at any glow plug (1) or battery voltage (V_{BAT}) is too low (2) (“battery undervoltage”)
8	One or more of the following failures (“module failure”): any switch is defect supply voltage (V_{VS}) is too low (“undervoltage”) supply voltage (V_{VS}) is too high (“overvoltage”) junction temperature (T_J) is too high charge pump voltage (V_{CP}) is too low (“charge pump undervoltage”) battery voltage (V_{BAT}) is too low (2) (“battery under voltage”)

1. overcurrent failures are stored until power-down
2. if battery voltage is too low (“battery under voltage”) bits 7 and 8 are high

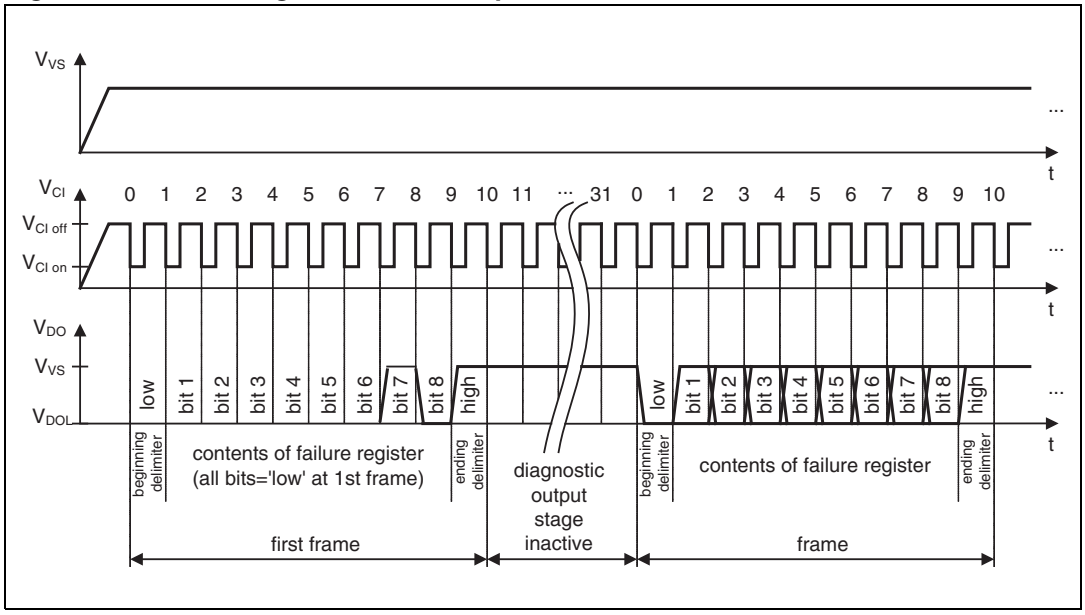
Bits 1 to 6 are assigned to the glow plugs. Depending on bit 7 they show open-load (bit 7 is low) or overcurrent failures (bit 7 is high). Bit 8 shows if there is any of the listed failures (“module failure”). In case of a battery under voltage failure bits 7 and 8 are high and all other bits are low as long as there is no overcurrent failure stored.

For transmitting the contents of the failure register the PWM signal applied to the CI pin is used as clock input: at any falling edge of the CI signal (see section “Control input”) the DO pin shows the value of the next bit of the bit stream after $t_{DO\ del}$.

Each transmission frame consists of a beginning delimiter (one low bit) followed by the 8 bits of the failure register beginning with bit 1. After the ending delimiter (one high bit) the diagnostic output stage is inactive and is resistively pulled up to V_{VS}.

The L9524C starts transmitting the first frame at the very first falling edge of the CI signal after power-on. Since at that time the contents of the failure register are clear the first 9 bits (beginning delimiter followed by the contents of the 8-bit failure register) which are transmitted are always low. The L9524C repeats transmission of the frame every 32 falling edges of the CI signal. Only during the time when the diagnostic output stage is inactive (i.e. between the transmission of two frames) the contents of the failure register can be written.

Figure 7. Serial diagnostic interface protocol



4.5 Current monitoring

The L9524C is able to monitor the current through 6 glow plugs by measuring the voltage drop across sense resistors. Therefore, there are 4 positive sense input pins (SP1, SP2, SP3, SP4) and 6 negative sense input pins (SN1, SN2, SN3, SN4, SN5, SN6). The sense input pins must be connected to the sense resistors according to the following table:

Table 9. Sense input pin connection

Sense resistor of glow plug	Positive sense input pin	Negative sense input pin
1	SP1	SN1
2	SP2	SN2
3	SP3	SN3
4	SP4	SN4
5	SP2	SN5
6	SP4	SN6

In relay mode (modes 1 and 2) the positive sense input pins are short-circuited since the relay is the only switch. In transistor mode (modes 3 to 6) glow plug 5 is switched with transistor 2 and glow plug 6 with transistor 4. Therefore only 4 positive sense input pins are necessary.

If the voltage drop across the sense resistor is less than ΔV_{OL} for at least $t_{OL\ fil}$ an open-load failure is detected as long as $V_{VS} > V_{VS\ ol}$. If it is greater than ΔV_{OC} (see below for definition) for at least $t_{OC\ fil}$ an overcurrent failure is detected and the corresponding switch is switched off and remains switched off until power-down. The threshold for overcurrent failures ΔV_{OC} can be varied by the voltage applied to the OCT pin (see section “Overcurrent threshold variation”).

In modes 1 to 4 the overcurrent threshold is constant with respect to the temperature ($TC_{OC} = 0$). But in modes 5 and 6 the overcurrent threshold increases linearly with the temperature ϑ to compensate the first-order temperature coefficient of the $R_{DS(on)}$ of the external power MOSFET’s which are used as sense resistors in these modes:

Equation 1

$$\Delta V_{OC} = \Delta V_{OC\ 0}\,(1 + TC_{OC}\,(\vartheta + 40°C)).$$

4.6 Switch monitoring

The L9524C monitors the voltages across the glow plugs (using the negative sense input pins SN1, SN2, SN3, and SN4) to detect if the corresponding switches work properly or not. A switch is detected as defect if it is switched on but the voltage across the corresponding glow plug(s) is less than V_{SD} for at least $t_{SD\ fil}$ or if it is switched off but the voltage across the glow plug(s) is greater than V_{SD} for at least $t_{SD\ fil}$.

4.7 Thermal shutdown

If the junction temperature becomes greater than T_{JSD} all glow plugs are switched off. They are switched on again if the junction temperature falls below T_{JSD}.

4.8 Gate drivers

The L9524C contains four gate drivers (Gx pins) for external n-channel power MOSFET’s in high-side configuration. Each gate driver provides a slope control by charging and discharging the gates of the external power MOSFET’s with constant currents ($I_{G\ on}$ or $I_{G\ off}$). To adjust the slopes these currents can be varied using the CUR pin (see section “Gate charge/discharge current variation”). The charging current source is supplied by an external capacitor connected to the charge pump output (CP) pin. The gate-to-source voltages are limited internally and without supply voltage (V_{VS}) the gates and the sources of the external power MOSFET’s are short-circuited.

During free-wheeling of inductive loads the gates of the external power MOSFET’s are clamped to $V_{G\ cl}$. As a result, the power MOSFET’s become conducting and the energy in the inductive loads is recirculated through the power MOSFET’s.

4.9 Relay output

In relay mode (modes 1 and 2) the IO pin is used as output pin to control an external relay driver (e.g. a low-side switch which drives the relay). If the output stage of the IO pin is switched on it behaves like a voltage source (V_{IO}) with output resistance R_{IO}. If it is switched off a pull-down current source is activated (I_{IO}). The relay output suppresses pulses shorter than $t_{IO\ sup}$ such that the relay can be permanently switched by applying appropriate PWM signals to the CI pin (see section “Control input”).

In transistor mode (modes 3 to 6) the IO pin is used as input pin. Left open it is pulled down to ground and the power regulation feature (see section “Power regulation”) is activated ($V_{IO} < V_{IO\ pr}$). To deactivate the power regulation feature the IO pin must be connected to the CUR pin ($V_{IO} = V_{CUR} > V_{IO\ pr}$).

4.10 Gate charge/discharge current variation

The CUR pin provides a constant current-limited output voltage V_{CUR}. The gate charge (or discharge) current is a multiple of the current flowing out of the CUR pin and can therefore be varied by applying a resistor to the CUR pin.

In order to select the mode of operation the IO pin and/or the MS pin may be connected to the CUR pin (see section “Modes”). The IO pin contains a pull-down current source and the MS pin contains a pull-up current source. These currents are compensated if the corresponding pin is connected to the CUR pin in order not to affect the gate charge/discharge current.

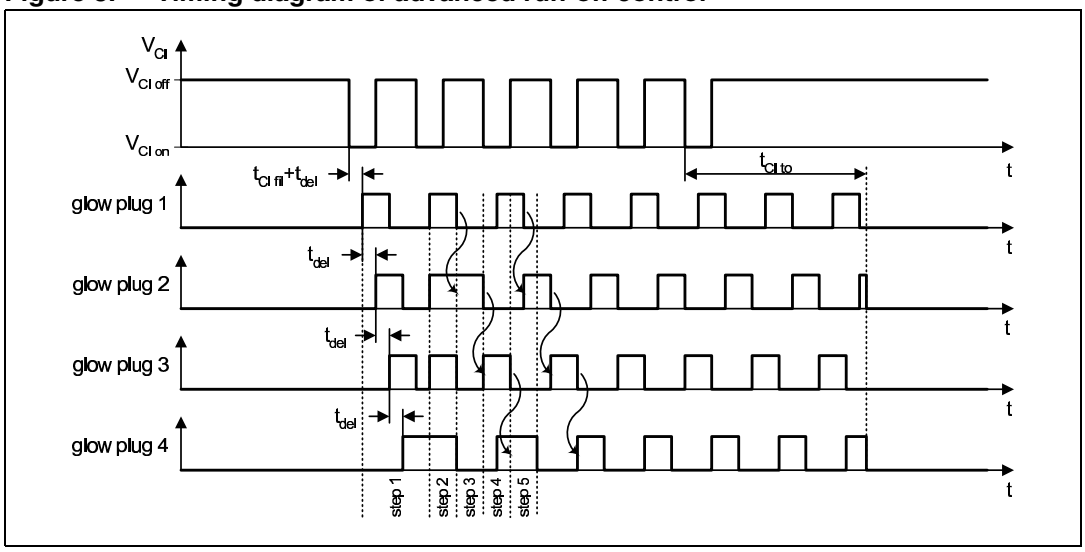
4.11 Overcurrent threshold variation

The overcurrent threshold ΔV_{OC} can be varied by connecting the OCT pin to an external resistive voltage divider between CUR pin and ground. If the OCT pin is left open it is pulled up to an internal supply voltage by a current source and a default value is used for the overcurrent threshold. This default value corresponds to the condition: $V_{OCT} = V_{CUR}/6$. In order not to de tune the voltage divider the pull-up current I_{OCT} source is deactivated when any glow plug is switched on.

4.12 Advanced run-off control

In transistor mode (modes 3 to 6) the glow plugs are switched by an advanced run-off control. The target is to minimize changes in the load current. Therefore, the PWM signals applied to the glow plugs are phase-shifted to each other. There is a 5-step start-up procedure at the beginning of a switching sequence. In step 1 the phase shift between the glow plugs is set to a fixed value t_{del}. Therefore, all glow plugs are switched on once in the first period of the PWM control input signal (CI) and are heated up quite simultaneously. During the start-up procedure the phase shift becomes a value equal to the on time of one glow plug. As a result, after the start-up procedure the glow plugs are switched on one after the other to get minimal changes in the load current.

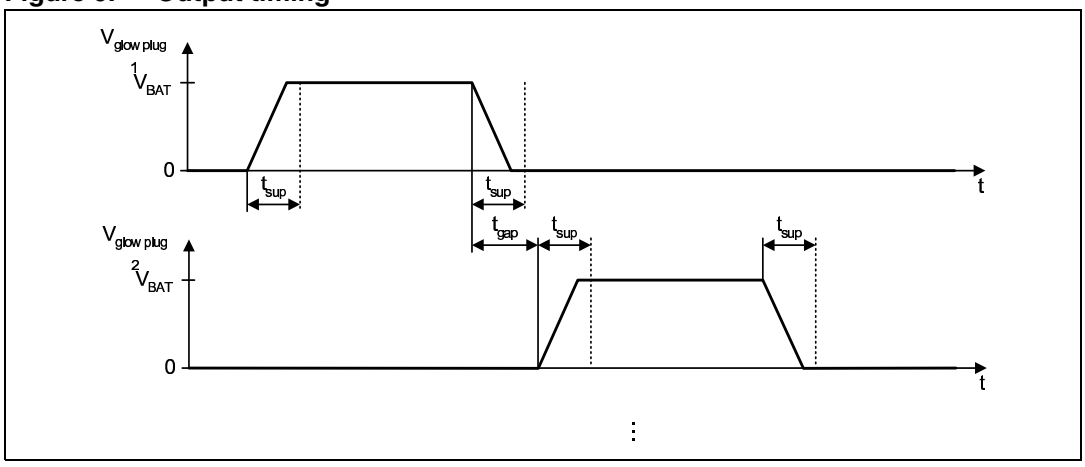
Figure 8. Timing diagram of advanced run-off control



4.13 Output timing

In transistor mode (modes 3 to 6) there is a delay t_{gap} between switching off one glow plug and switching on the next one to avoid overlaps. Additionally, failures occurring during the slope (i.e. in the time period t_{sup} after switching) are suppressed in all modes.

Figure 9. Output timing



4.14 Power regulation

The power through each glow plug (here expressed by V_{RMS} which is the root-mean-square voltage across one glow plug) depends on the battery voltage V_{BAT} and the duty cycle $t_{G\ on}/T_G$ of the PWM signal applied to the external power MOSFET's:

Equation 2

$$V_{RMS} = V_{BAT} \cdot \sqrt{\frac{t_{G\ on}}{T_G}}$$

In order to regulate the power through the glow plugs the L9524C measures V_{BAT} and adjusts $t_{G\ on}/T_G$ of the gate drivers (G1...4) such that $V_{RMS} = V_{RMS\ ref}$, where $V_{RMS\ ref}$ represents the desired power through each glow plug.

The desired power $V_{RMS\ ref}$ is given by the input duty cycle $t_{CI\ on}/T_{CI}$ which represents the desired output duty cycle at a nominal battery voltage of 12V:

Equation 3

$$V_{RMS\ ref} = 12V \cdot \sqrt{\frac{t_{CI\ on}}{t_{CI}}}$$

As a result, the actual output duty cycle of the gate drivers is given by:

Equation 4

$$\frac{t_{G\ on}}{T_G} = \left(\frac{12V}{V_{BAT}}\right)^2 \cdot \frac{t_{CI\ on}}{T_{CI}}$$

Note: The L9524C *varies both the on time $t_{G\ on}$ and the period T_G of the PWM output signal to vary the duty cycle $t_{G\ on}/T_G$.*

The accuracy of the power regulation is given by $\Delta V_{RMS} = V_{RMS} - V_{RMS\ ref}$.

The output jitter (electrical characteristics Item 8.8) is not taken in consideration while the average is zero over some periodes.

5 Application diagrams

Figure 10. Mode 1: relay mode, go/no-go diagnostic interface protocol

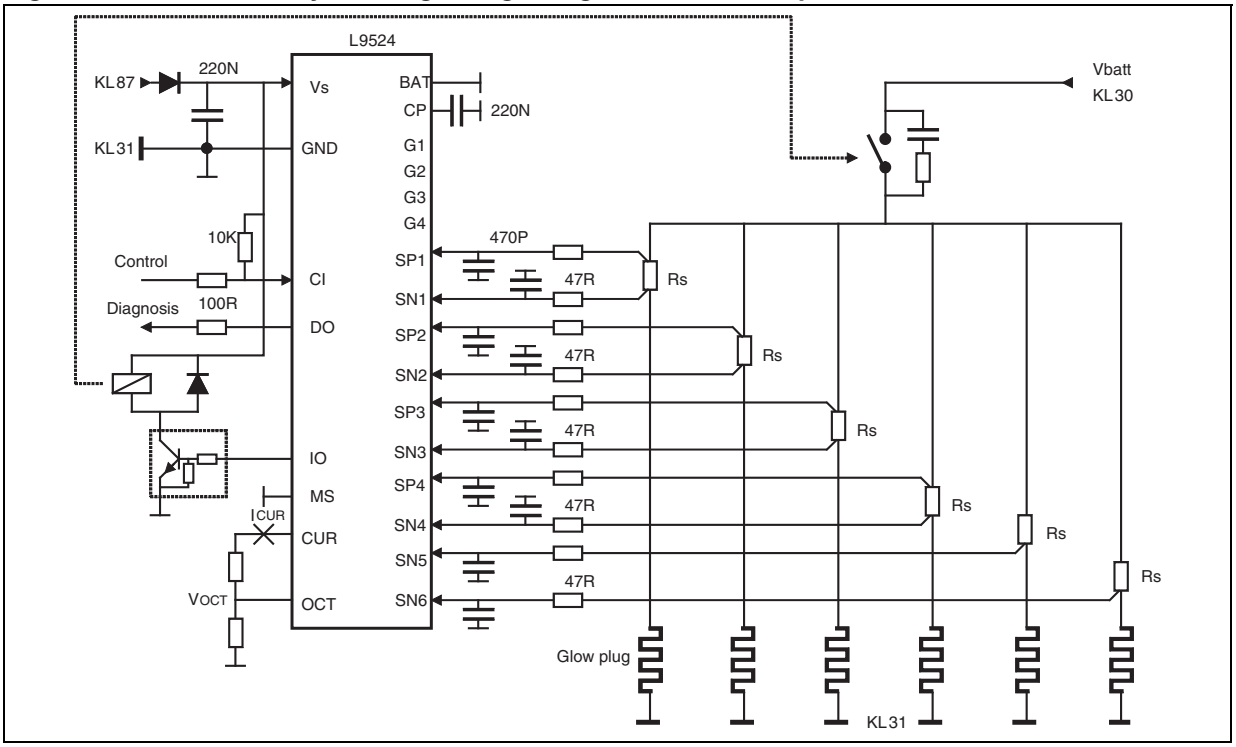


Figure 11. Mode 2: relay mode, serial diagnostic interface protocol

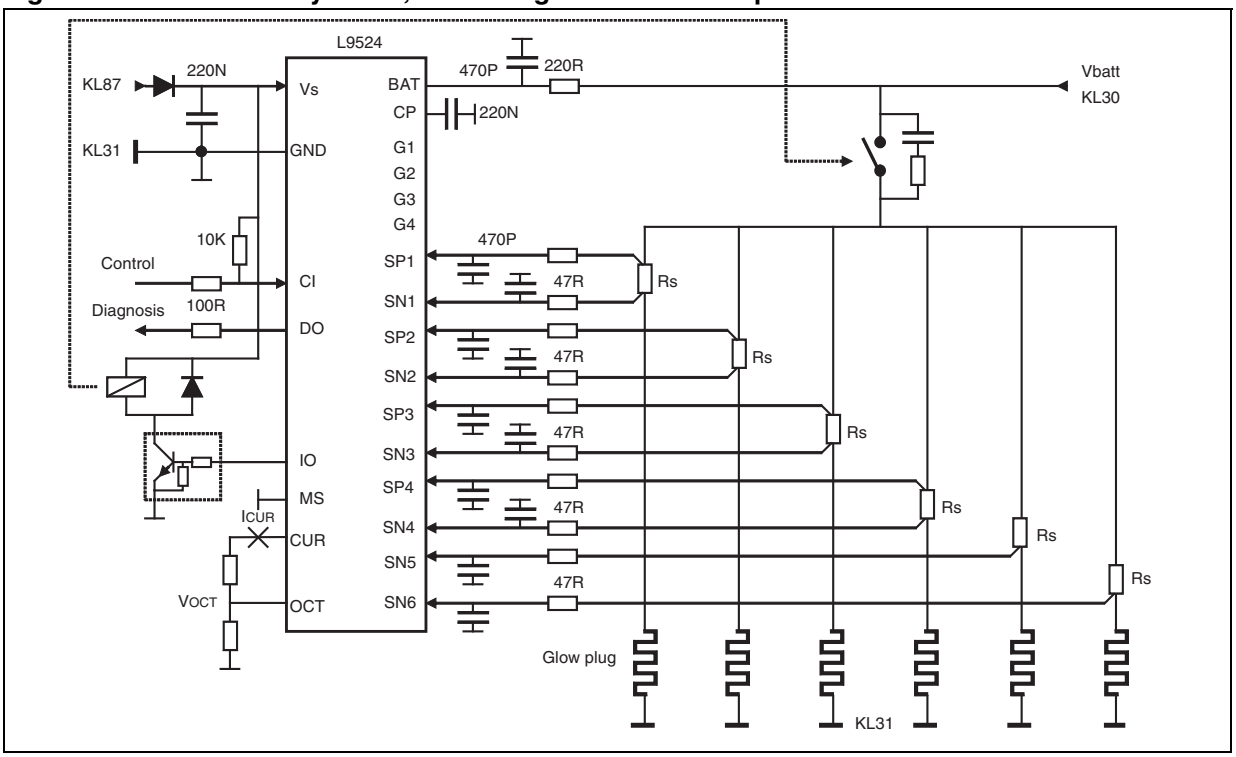


Figure 12. Mode 3: transistor mode, shunt sense, no power regulation

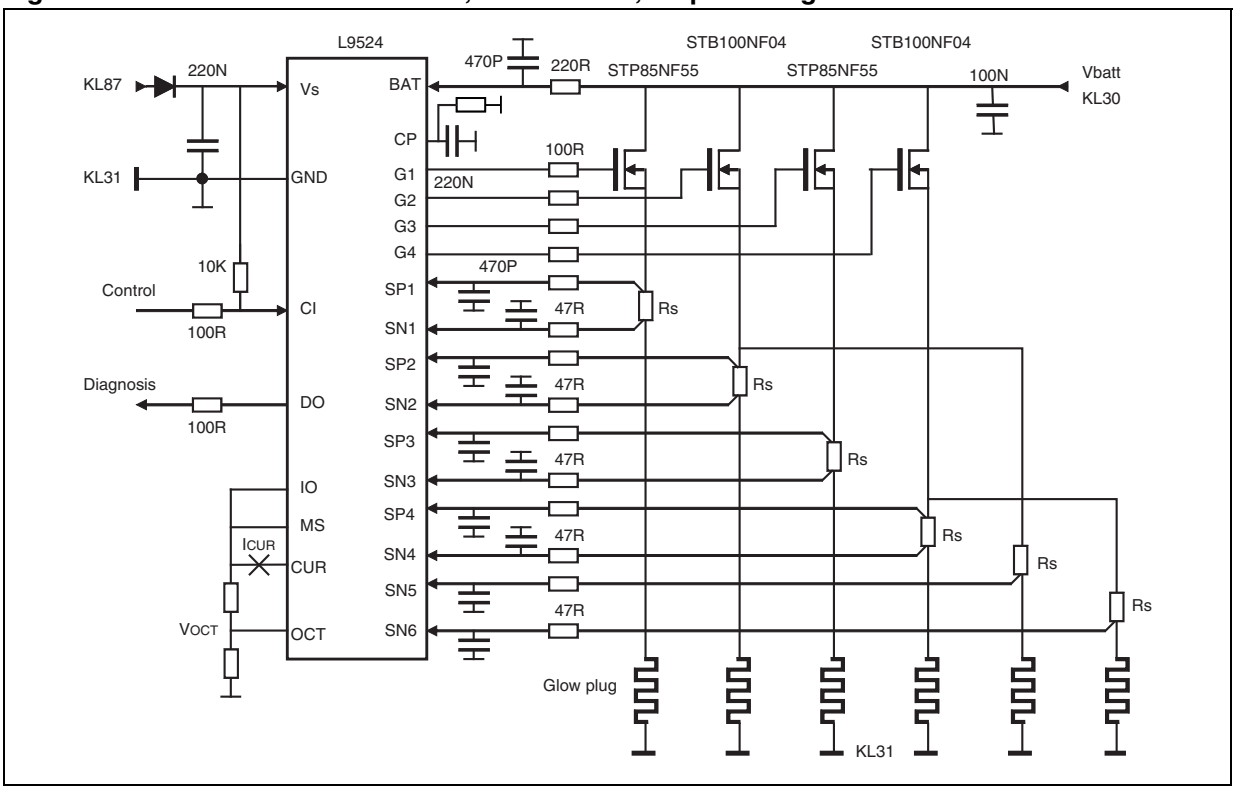


Figure 13. Mode 4: transistor mode, shunt sense, power regulation

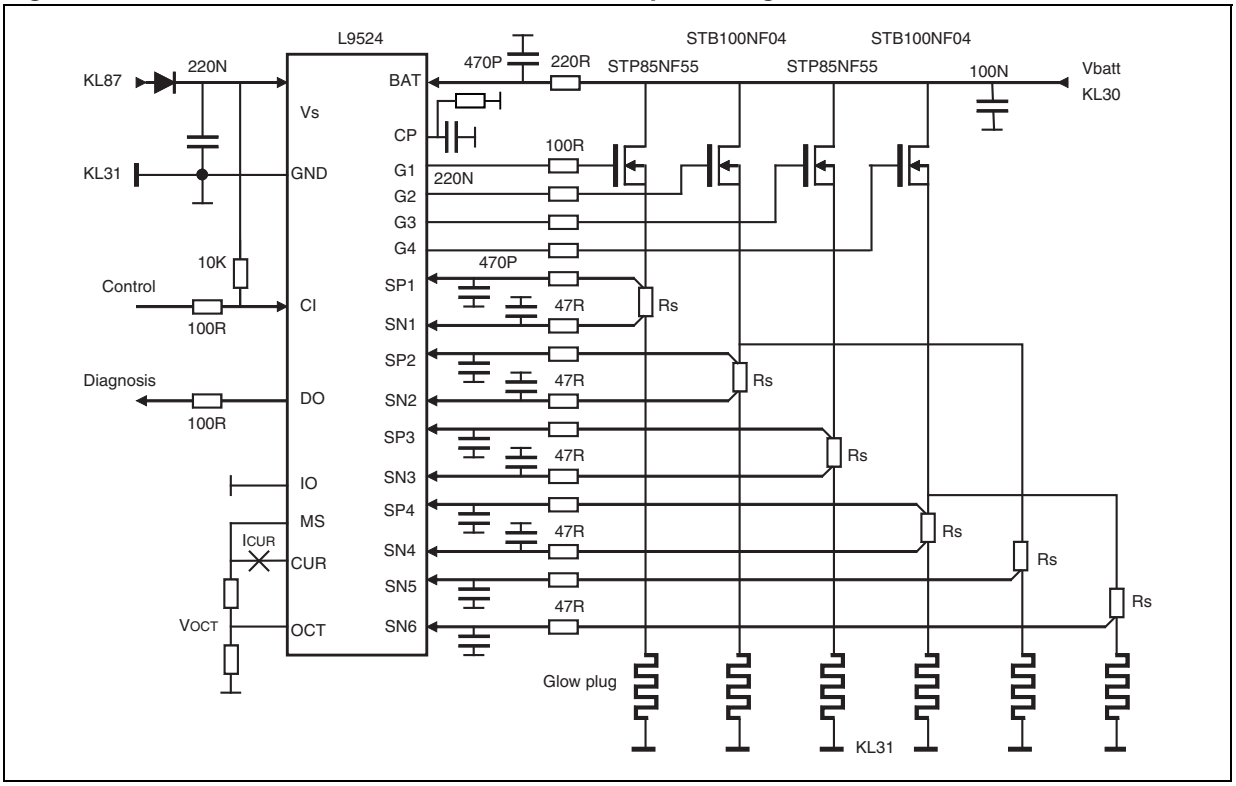


Figure 14. Mode 5: transistor mode, transistor sense, no power regulation

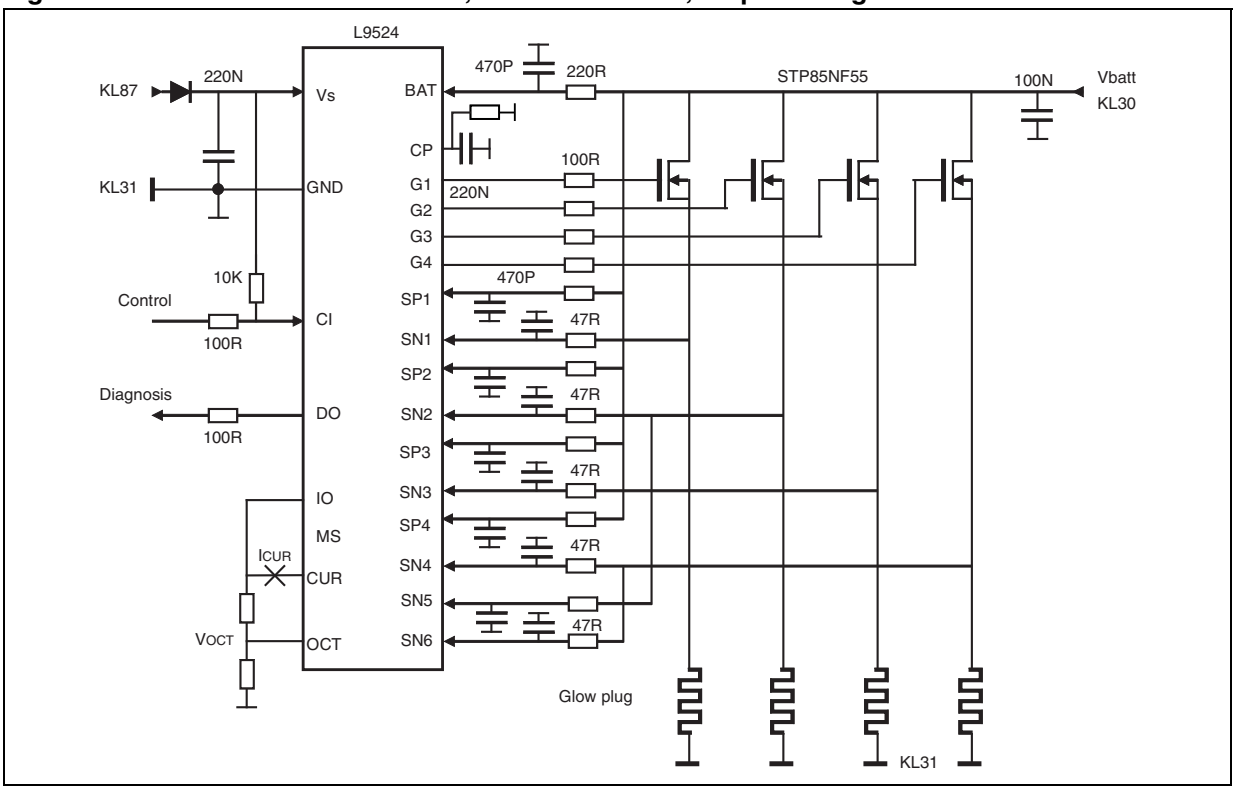
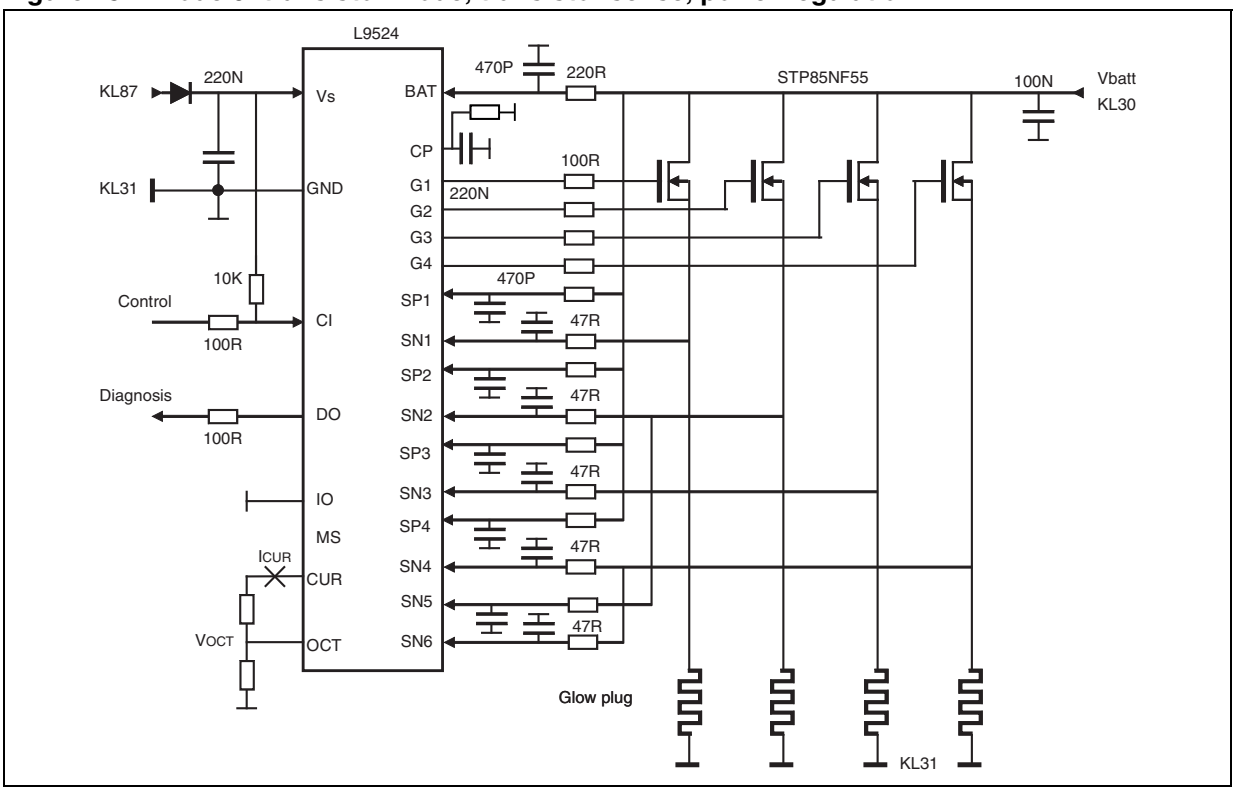


Figure 15. Mode 6: transistor mode, transistor sense, power regulation



6 Package information

In order to meet environmental requirements, ST (also) offers these devices in ECOPACK® packages. ECOPACK® packages are lead-free. The category of second Level Interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label.

ECOPACK is an ST trademark. ECOPACK specifications are available at: www.st.com.

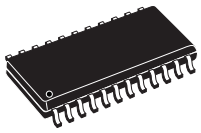
Figure 16. SO24 mechanical data and package dimensions

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A	2.35		2.65	0.093		0.104
A1	0.10		0.30	0.004		0.012
B	0.33		0.51	0.013		0.200
C	0.23		0.32	0.009		0.013
D (1)	15.20		15.60	0.598		0.614
E	7.40		7.60	0.291		0.299
e		1.27			0.050	
H	10.0		10.65	0.394		0.419
h	0.25		0.75	0.010		0.030
L	0.40		1.27	0.016		0.050
k	0° (min.), 8° (max.)					
ddd			0.10			0.004

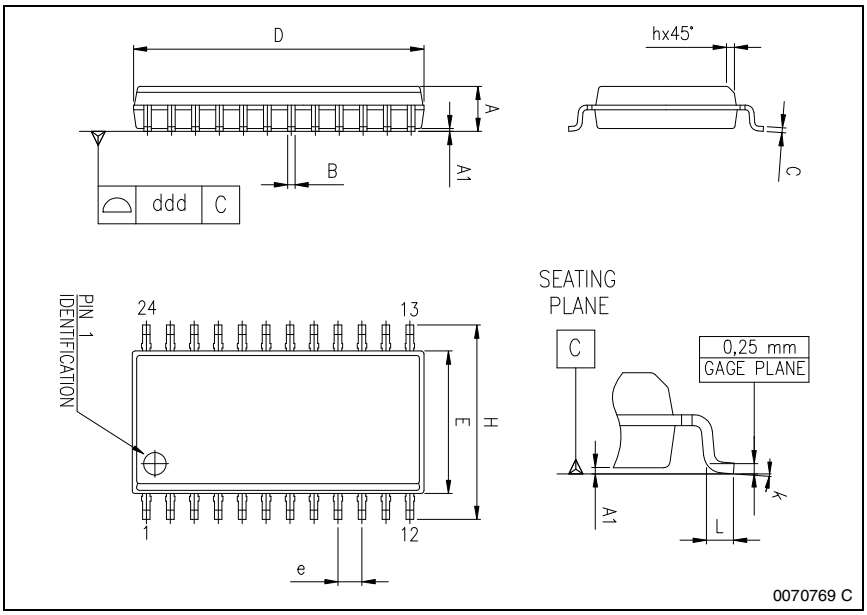
(1) "D" dimension does not include mold flash, protusions or gate burrs. Mold flash, protusions or gate burrs shall not exceed 0.15mm per side.

OUTLINE AND MECHANICAL DATA

Weight: 0.60gr



SO24



7 Revision history

Table 10. Document revision history

Date	Revision	Description of changes
22-Sep-2006	1	Initial release
29-Sep-2007	2	Updated the *Section 3.3: Electrical characteristics*.
9-Jan-2008	3	Modified the *Figure 5* and *Figure 7*. Added the sub-title *Section 4.3: Control input*. Modified the values of the items 1.8, 6.4 and 7.2, and the parameter definition of the item 8.6 in the *Section 3.3: Electrical characteristics*.
17-Sep-2013	4	Updated Disclaimer

Please Read Carefully:

Information in this document is provided solely in connection with ST products. STMicroelectronics NV and its subsidiaries (“ST”) reserve the right to make changes, corrections, modifications or improvements, to this document, and the products and services described herein at any time, without notice.

All ST products are sold pursuant to ST’s terms and conditions of sale.

Purchasers are solely responsible for the choice, selection and use of the ST products and services described herein, and ST assumes no liability whatsoever relating to the choice, selection or use of the ST products and services described herein.

No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted under this document. If any part of this document refers to any third party products or services it shall not be deemed a license grant by ST for the use of such third party products or services, or any intellectual property contained therein or considered as a warranty covering the use in any manner whatsoever of such third party products or services or any intellectual property contained therein.

UNLESS OTHERWISE SET FORTH IN ST’S TERMS AND CONDITIONS OF SALE ST DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY WITH RESPECT TO THE USE AND/OR SALE OF ST PRODUCTS INCLUDING WITHOUT LIMITATION IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION), OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

ST PRODUCTS ARE NOT DESIGNED OR AUTHORIZED FOR USE IN: (A) SAFETY CRITICAL APPLICATIONS SUCH AS LIFE SUPPORTING, ACTIVE IMPLANTED DEVICES OR SYSTEMS WITH PRODUCT FUNCTIONAL SAFETY REQUIREMENTS; (B) AERONAUTIC APPLICATIONS; (C) AUTOMOTIVE APPLICATIONS OR ENVIRONMENTS, AND/OR (D) AEROSPACE APPLICATIONS OR ENVIRONMENTS. WHERE ST PRODUCTS ARE NOT DESIGNED FOR SUCH USE, THE PURCHASER SHALL USE PRODUCTS AT PURCHASER’S SOLE RISK, EVEN IF ST HAS BEEN INFORMED IN WRITING OF SUCH USAGE, UNLESS A PRODUCT IS EXPRESSLY DESIGNATED BY ST AS BEING INTENDED FOR “AUTOMOTIVE, AUTOMOTIVE SAFETY OR MEDICAL” INDUSTRY DOMAINS ACCORDING TO ST PRODUCT DESIGN SPECIFICATIONS. PRODUCTS FORMALLY ESCC, QML OR JAN QUALIFIED ARE DEEMED SUITABLE FOR USE IN AEROSPACE BY THE CORRESPONDING GOVERNMENTAL AGENCY.

Resale of ST products with provisions different from the statements and/or technical features set forth in this document shall immediately void any warranty granted by ST for the ST product or service described herein and shall not create or extend in any manner whatsoever, any liability of ST.

ST and the ST logo are trademarks or registered trademarks of ST in various countries.
Information in this document supersedes and replaces all information previously supplied.
The ST logo is a registered trademark of STMicroelectronics. All other names are the property of their respective owners.

© 2013 STMicroelectronics - All rights reserved

STMicroelectronics group of companies

Australia - Belgium - Brazil - Canada - China - Czech Republic - Finland - France - Germany - Hong Kong - India - Israel - Italy - Japan - Malaysia - Malta - Morocco - Philippines - Singapore - Spain - Sweden - Switzerland - United Kingdom - United States of America

www.st.com