L9374LF

Four channel valve driver

Datasheet - production data

PowerSO-36

Features

- Four protected low-side drivers with diagnostics
  - Two 140 mΩ PWM controlled outputs (Q1 & Q2)
  - Two 250 mΩ current controlled outputs with 6 % accuracy (Q3 & Q4)
- All outputs with 35 V Zener Clamp
- Programmable output timer
- Clock monitor
- Integrated recirculation diodes
- 16 bit serial peripheral interface, up to 5 MHz with diagnosis
- Battery compatible supply voltage
- Detailed load diagnosis
  - Over load protection
  - Open load (off-state)
  - Undercurrent
  - Undervoltage
  - Temperature warning and shutdown
  - Power or signal GND loss
  - Freewheeling diode loss
  - Silent valve driver test

Description

The L9374LF is a SPI (serial peripheral interface) controlled four channel low side driver with integrated recirculation diodes.

The output duty cycle (all channels) / current regulation level (Q3 & Q4 only) can be programmed individually. It is possible to program two consecutive output duty cycles or target currents per channel as well as an individual duration time for each channel actuation.

Table 1. Device summary

Order code	Package	Packing
L9374LF	PowerSO-36	Tube
L9374TRLF	PowerSO-36	Tape and reel

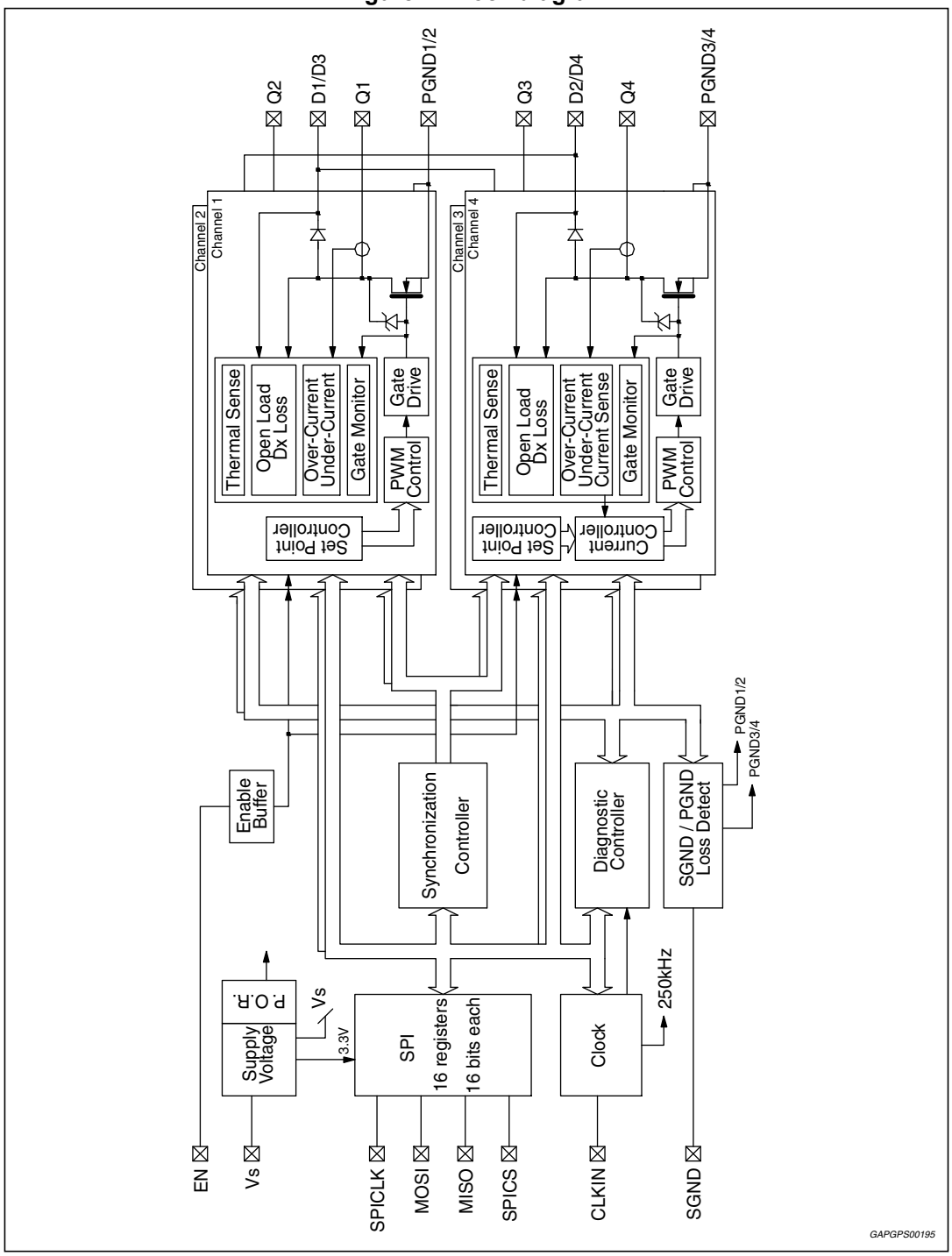
Contents

List of tables

List of figures

1 Block diagram

Figure 1. Block diagram



2 Pins description

Figure 2. PowerSO-36 pins connection (top view)

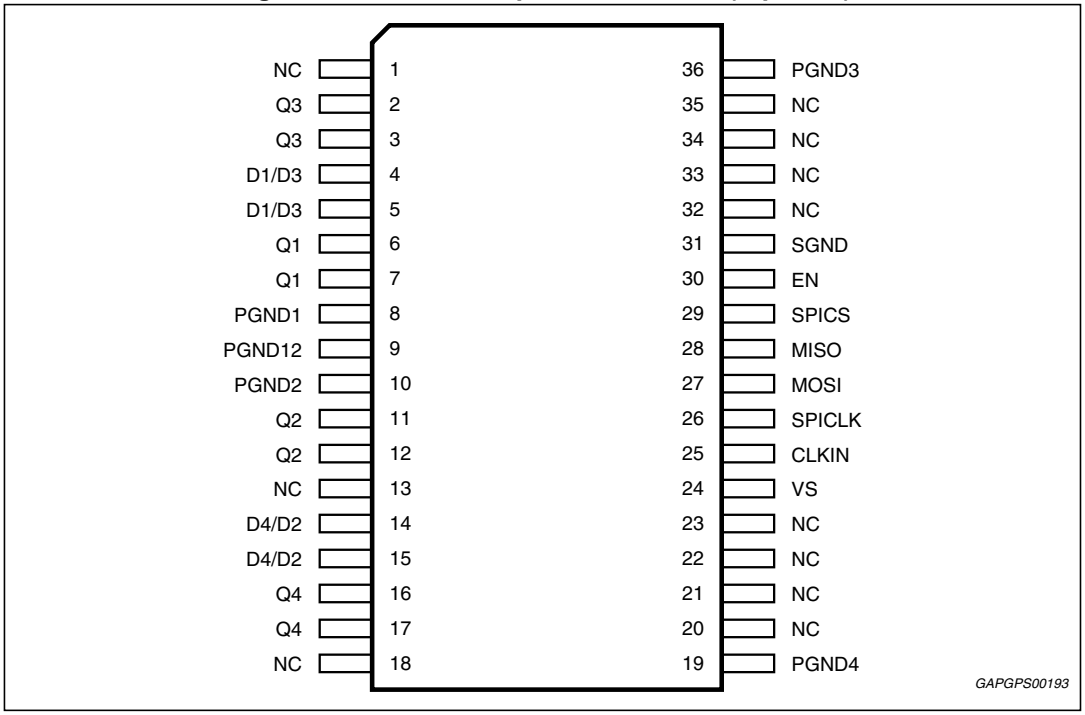


Table 2. Pins description

Pin #	Pin name	Description
1	PGND	Not connected/Power ground.
2	Q3	Output.
3	Q3	Output.
4	D1/D3	Free wheeling diode.
5	D1/D3	Free wheeling diode.
6	Q1	Output.
7	Q1	Output.
8	PGND1	Power ground of the output driver 1& 2.
9	PGND12	Power ground of the output driver 1& 2.
10	PGND2	Power ground of the output driver 1& 2.
11	Q2	Output.
12	Q2	Output.
13	N.C.	Not connected.
14	D4/D2	Free wheeling diode.
15	D4/D2	Free wheeling diode.
16	Q4	Output.

Table 2. Pins description (continued)

Pin #	Pin name	Description
17	Q4	Output.
18	PGND	Not connected/Power ground.
19	PGND4	Power ground of the output driver 4.
20	N.C.	Not connected.
21	N.C.	Not connected.
22	N.C.	Not connected.
23	N.C.	Not connected.
24	VS	Supply pin.
25	CLKIN	Input for precise clock.
26	SPICLK	SPI communication clock.
27	MOSI	Master Out Slave In for SPI communication.
28	MISO	Master In Slave Out for SPI communication.
29	SPICS	SPI chip select.
30	EN	Enable.
31	SGND	Signal ground.
32	N.C.	Not connected.
33	N.C.	Not connected.
34	N.C.	Not connected.
35	N.C.	Not connected.
36	PGND3	Power ground of the output driver 3.

3 Electrical specifications

3.1 Absolute maximum ratings

Table 3. Absolute maximum ratings

Symbol	Parameter	Min.	Max.	Unit
V_s	Supply voltage	-0.3	38	V
V_{Dx}	Freewheeling diode voltage	-0.3	35	V
V_{Qx}	Output voltage	-0.3	Internally Clamped	V
V_{EN} V_{SPICLK} V_{SPICS} V_{MOSI} V_{MISO} V_{CLKIN}	Enable voltage SPI clock voltage SPI chip select voltage SPI MOSI voltage SPI MISO voltage SPI clock input voltage	-0.3	6	V
$I_{Q1; 2}$	Output current at reversal voltage	-	-4	A
$I_{Q3; 4}$		-	-2	A
I_{EN_CL} I_{SPICLK_CL} I_{SPICS_CL} I_{MOSI_CL} I_{CLKIN_CL}	Input clamping currents (static) Input clamping currents (dynamic)	- 3 -10	+ 3 +10	mA
T_{amb}	Ambient operating temperature	-40	+125	°C

Definition: Current flowing into the L9374LF are considered positive -> “+"
Current flowing out of the L9374LF are considered negative -> “-"

Warning: Transients beyond this limit will cause currents into ESD structures which must be limited externally to ±10 mA (maximum energy to be dissipated: 2 mJ).

3.2 ESD susceptibility

3.2.1 HBM

ESD susceptibility HBM according to EIA/JESD 22-A 114B

Table 4. HBM

Pin	Condition	Min.	Max.	Unit
All pins	-	± 2	-	kV
Output pins D_X; Q_X;	PGND12, PGND3, PGND4, LGND and GND are connected together.	± 4	-	kV

3.2.2 MM

ESD susceptibility according to EIA/JESD22-A115-A

Table 5. MM

Parameter	Condition	Min.	Max.	Unit
Machine model (MM)	All pins	± 250	-	V

3.3 Electrical characteristics

V_S = 5.2 to 20 V; -40 °C ≤ T_j ≤ 175 °C, unless otherwise specified.

Function is guaranteed until thermal shutdown threshold, T_{SD};

3.3.1 Supply current

Table 6. Supply current

Symbol	Parameter	Condition	Min	Typ	Max	Unit
I_{VS}	Supply current	Vs = 13.5 V @+175 °C @+25 °C @-40 °C	 2.0 - -	 - 7.5 -	 - - 9.0	mA
V_s	Supply voltage operating range	-	5.2	-	20	V

3.3.2 Output power stages

The output power stages consist of an MOSFET and a freewheeling diode. Each output contains diagnostic and protection circuitry. Additional current sensing is present in the current regulated outputs (for more details see *Section 4.7: Output driver*).

Figure 3. Output power stages Q1/Q2

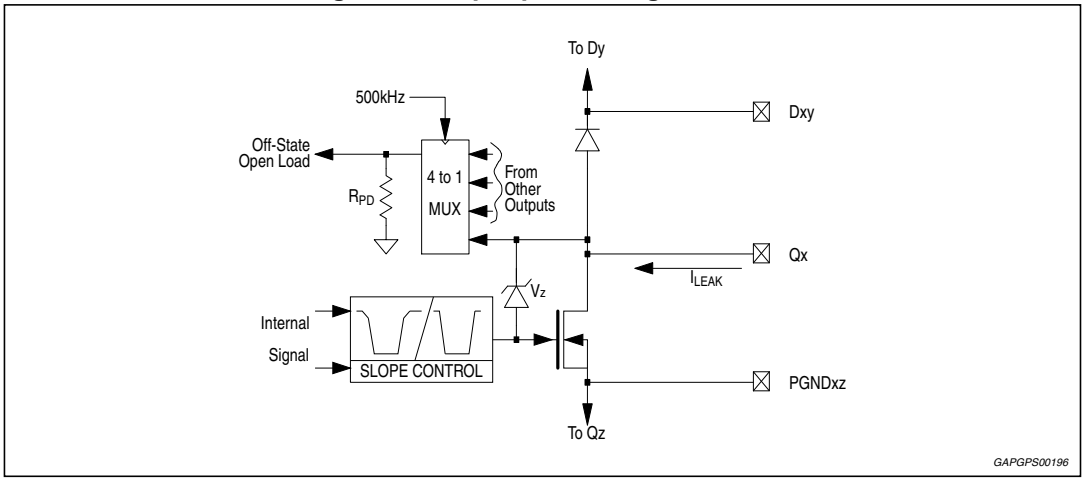
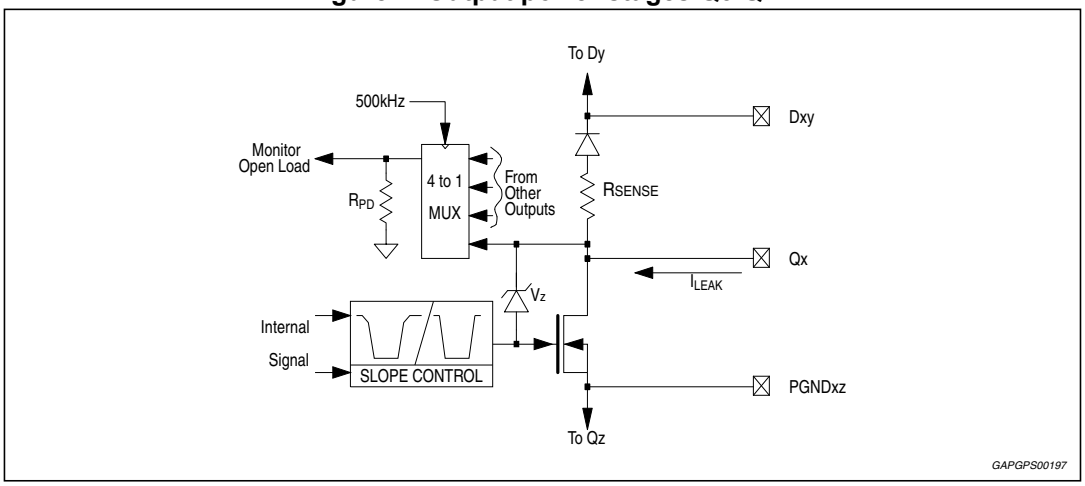


Table 7. Output power stages

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
$R_{ON}(Q_1/Q_2)$	Static drain-source on-resistance Q_1 / Q_2	I_Q = 1 A (TK: 0.58 % / K; Typ @ RT)	60	140	390	mΩ
$R_{ON}(Q_3/Q_4)$	Static drain-source on-resistance Q_3 / Q_4	I_Q = 1 A (TK: 0.58 % /K; Typ @ RT)	80	250	520	mΩ
V_Z	Z-diode clamping voltage	I_Q = current limitation	35	-	40	V
R_{PD}	Output pull down resistor (multiplexed to the 4 outputs sequentially)(1)	EN = 1	20	40	100	kΩ
I_{LEAK}	Output leakage current	V_Q = 20 V; EN = 0 V T_j =130 °C T_j = 25 °C	-	-	5 1	µA µA

1. R_{PD} is sequentially connected to each output for 2 µs (8 µs period) for the purpose of detecting off-state open load.

Figure 4. Output power stages Q3/Q4



3.3.3 Freewheeling diode

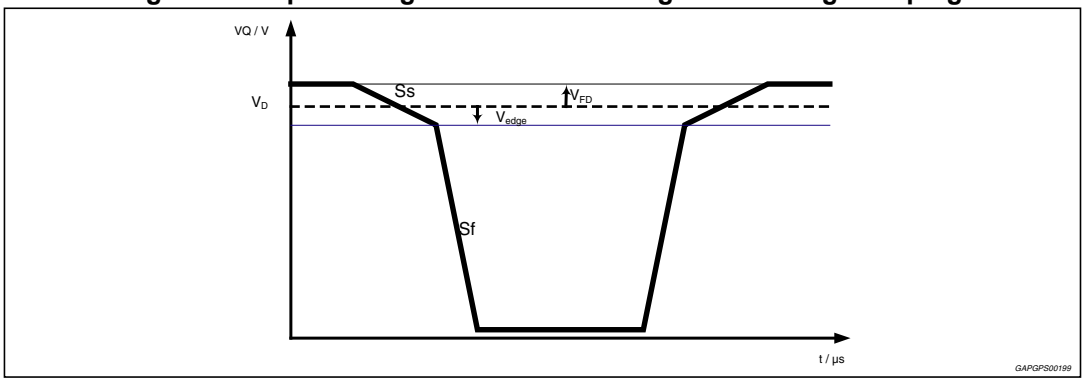
Table 8. Freewheeling diode electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
$V_{FD1/2}$	Forward voltage of free wheeling diodes D_1 / D_2	I_{FD} = -1.5 A	0.5	0.75	1.75	V
$V_{FD3/4}$	Forward voltage of free wheeling path	D3, D4 @-250 mA	0.5	1.0	1.5	V
		D3, D4 @-1.8 A	1.6		3.6	V
R_{sense}	Q_3/Q_4 Sense resistor	Calculated: ($V_{FD\_1.8A}$-V_{FD_250mA})/1.55 A	-	1	-	Ω
$R_{D1/3}$	Resistor D_{13}-Pin	$V_Q < V_D < 18$ V (Typ @ T_j = 25 °C)	100	240	700	kΩ
$I_{leak\_Dx\_0}$	Leakage current into Dx-Pin D_{13}	EN = 0	5	-	160	µA
$I_{leak\_Dx\_1/0}$	Leakage current into Dx-Pin D_{13} D_{24}	EN = 1 I_{DAC} = 0A	90	70	400	µA
$I_{leak\_Dx\_1/1.8}$	Leakage current into Dx-Pin D_{13} D_{24}	EN = 1 I_{DAC} = 1.8A	90	-	2400	µA

3.3.4 Output timing characteristics

The DMOS outputs have controlled slopes to minimize EME. The Edge Shaping option is programmed via SPI (See *Edge shaping (EDGE_SH)*; without edge shaping, the slope is fixed to 10V/µs in both directions.

Figure 5. Output timing characteristics diagram with edge shaping



Where:

- V_D: Valve supply voltage
- V_{FD}: Forward voltage drop across the recirculation diode
- V_{EDGE}: Voltage Sf to Ss slope transition
- Ss: Slow slope
- Sf: Fast slope

Table 9. Output timing electrical characteristics(1)

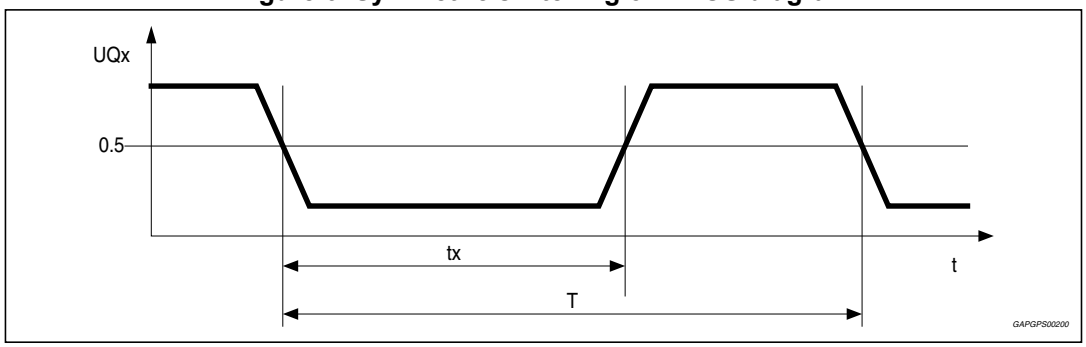
Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
V_{edge}	Edge shaping threshold	measured from V_D	-2.2	-	-1	V
Sf_Q_1/Q_2	Sf output on/off slope fast Q_1/Q_2	V_D = 20 V I_{load}=1.5 A resistive load	3	10	17	V/µs
Ss_Q_1/Q_2	Ss output on/off slope slow Q_1/Q_2		2	4	6	V/µs
Sf_Q_3/Q_4	Sf output on/off slope fast Q_3/Q_4		6	13	20	V/µs
Ss_Q_3/Q_4	Ss output on/off slope slow Q_3/Q_4		2.5	5	7.5	V/µs

1. See *Figure 5* for waveform.

The slope is defined between 20 % and 80 % of the edge.

Symmetric switching of DMOS

Figure 6. Symmetric switching of DMOS diagram



A Symmetric switching is present to ensure a reliable PWM at the output.

Table 10. Symmetric switching of DMOS electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
t_{sym1}	Symmetry II with edge shaping	tx-dc · T< 1.5 µs dc = 50 % V_Q = 10 V	-1.0	-	2.0	µs
t_{sym2}	Symmetry II without edge shaping		0	-	3.0	µs

3.3.5 PWM output behavior

(refer to *Section 4.4: Set-point controller* for details)

Table 11. PWM output behavior characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
f_Q_x	Output frequency	-	-2 %	4	+2 %	kHz
DC	Duty range	-	0	-	100	%
DC_{RES}	Duty resolution of f_A	-	-	0.2	-	%
N_{RES}	Number of bits for duty resolution/ target current value	-	-	9	-	-

Table 11. PWM output behavior characteristics (continued)

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
$t(n)_{RES}$	Resolution of duration Add. 0 bit D9 = 0 Add. 0 bit D9 = 1	1/f_A	-	 250 500	-	 µs µs
N_{Bit}	Number of bits for duration	-	-	5	-	-
$t(n)_{MAX}$	Max. Duration Add. 0 bit D9 = 0 Add. 0 bit D9= 1	 (2^5-1) x 250 µs (2^5-1) x 500 µs	-	-	 7.75 15.5	 ms ms

3.3.6 Q3 / Q4 (current controller)

(refer to *Section 4.5: Current controller* for details)

Table 12. Q3 / Q4 (current controller) electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
$I_{Q3/Q4}$	Current range	-	0		1.8	A
$I_{Q3/Q4\_res}$	Current resolution	-	-	3.5	-	mA
$I_{Q3/Q4\_acc}$	Current accuracy	I_{load} = 0 mA to 400 mA I_{load} > 400 mA	-	-	±24 ±6	mA %

3.3.7 Logic inputs / outputs

Figure 7. Logic inputs

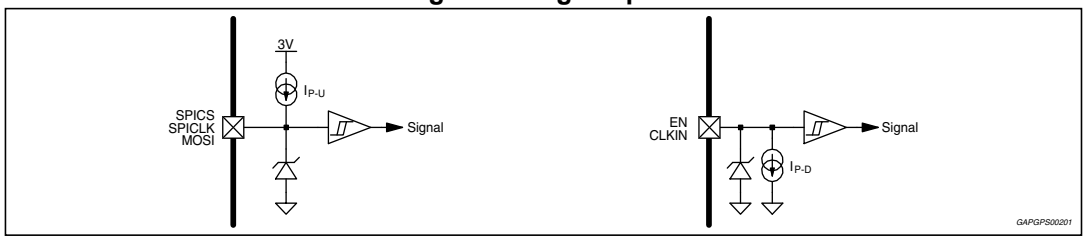


Table 13. Logic inputs electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
V_{In_low}	Input threshold	-	-0.3	-	1.0	V
V_{In_high}	Input threshold	-	2.0	-	3.5	V
$V_{In\text{-}hys}$	Input threshold hysteresis	-	50	100	350	mV
$I_{P\text{-}U}$	Internal pull-up current source for SPICS, SPICLK, MOSI	0 V ≤ $V_{In\text{-}xy}$ ≤ 2 V	-12	-30	-60	µA
$I_{P\text{-}D}$	Internal pull-down current source for EN, CLKIN	1 V ≤ $V_{In\text{-}xy}$ ≤ 3.45 V	+12	+30	+60	µA
C_{in}	Input capacitance	Designed but not tested	3.5	-	7.5	pF

3.3.8 Logic outputs (MISO)

Figure 8. Logic outputs (MISO) circuit

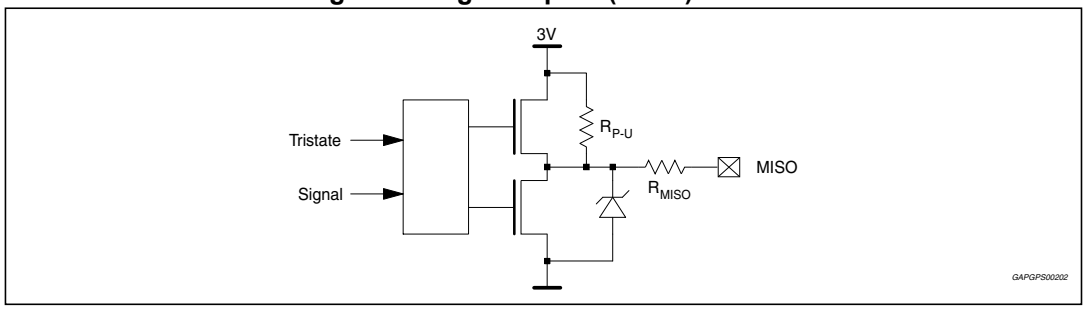


Table 14. Logic outputs (MISO) electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
V_{MISO_L}	MISO low voltage	$I_{Out-xy} \leq 25$ µA; $C_L \leq 30$ pF	0	-	0.4	V
V_{MISO_H}	MISO high voltage	$I_{Out-xy} \leq -25$ µA;	2.5	3.3	3.45	V
$R_{MISO-ON}$	MISO ON resistance	$R_{ON}+R_{MISO}$	40	100	400	Ω
R_{P-U}	MISO pull up resistor	SPICS = high → MISO in tristate mode	50	120	300	kΩ
C_{in}	Input capacitance	designed but not tested	3.5	-	7.5	pF

3.3.9 Diagnostic functions at output stage

(refer to *Section 4.8: Diagnostics* for details)

Table 15. Diagnostic functions at output stage electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
V_{OL}	Open load threshold	output off	0.3	0.33	0.39	x VS
I_{UC}	Undercurrent threshold	output on	50	100	140	mA
T_{SD}	Temperature shut down threshold(1)	-	180	200	220	°C
T_W	Temperature warning	-	160	180	200	°C
ΔT_{WSD}	Difference between T_W and T_{SD}	T_{SD}-T_W	10	-	40	°C
$D_{x\ loss}$	Supply loss threshold	-	32	-	39	V
$I_{OC1(1/2)}$	Overcurrent threshold 1 Q_1/Q_2	OC_TH_Qx = ‘01’	5	7.5	9	A
$I_{OC2(1/2)}$	Overcurrent threshold 2 Q_1/Q_2	OC_TH_Qx = ‘10’	7	8.5	10	A
$I_{OC(3/4)}$	Overcurrent threshold Q_3/Q_4	-	3	5	8	A
V_{G_ON}	Gate monitoring threshold	Internal node	2.5	-	-	V
V_{G_OFF}	Gate monitoring threshold	$I_Q > 15$ mA, Internal node	-	-	1	V

1. Monitoring is only active if the output is on.

3.3.10 General diagnostic functions

(refer to *Section 4.8: Diagnostics* for details)

Table 16. General diagnostic functions electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
V_{UV}	Under voltage threshold	(VS-pin)	3.0	-	5.2	V
V_{SG_L}	Signal GND loss threshold	-	0.2	0.4	0.6	V
V_{PG_L}	Power GND loss threshold	-	0.5	-	2.5	V
V_{PG_Lh}	Power GND loss hysteresis	-	-	1.0	-	V

"

Table 17. CLKIN-monitoring characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{CLKIN_H250}	CLKIN monitoring @ 250 kHz-mode set SPI bit	frequency too high	300	-	760	kHz
f_{CLKIN_L250}	CLKIN monitoring @ 250 kHz-mode set SPI bit	frequency too low	90	-	190	kHz
f_{CLKIN_H1M}	CLKIN monitoring @ 1 MHz-mode set SPI bit	frequency too high	1.20	-	3.04	MHz
f_{CLKIN_L1M}	CLKIN monitoring @ 1 MHz-mode set SPI bit	frequency too low	0.36	-	0.76	MHz
f_{CLKIN_OK}	CLKIN monitoring clear SPI bit	CLKIN frequency ok	-	250 1	-	kHz MHz

3.3.11 Filtering times

Table 18. Failure filtering times characteristics

Symbol	Parameter[1]	Condition	Min.	Typ.	Max.	Unit
t_{OL}	Openload filtering time	outputs off	20	44	70	µs
t_{UC}	Under current filtering time	-	10	20	40	µs
t_{OVL}	Overload switch-off delay time	-	10	20	40	µs
t_{SD}	Thermal shutdown delay time	-	10	40	80	µs
t_{TW}	Thermal warning filtering time	-	10	20	40	µs
t_{DX_L}	Dx loss filtering time	-	1	2	5	µs
t_{PGND_L}	Power GND loss filtering time	-	10	20	40	µs
t_{SGND_L}	Signal GND loss filtering time	-	10	20	40	µs
$t_{\_EN\_F}$	EN filtering time[2]	-	1.5	2	2.5	µs
t_{CLK_F}	CLKIN-failure detection time	-	140	200	310	µs
t_{CURR_F}	Current not reachable failure filtering time	-	7.75	8	8.25	ms

1. All parameters based on valid CLKIN (250 kHz / 1 MHz) signal.
2. Digital filter only for falling edges and analog filter for both edges.

Table 19. SVDT test timing

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
t_x	Minimum passing test time	SVDT Enabled I_Qx < I_{UC}	90	100	110	µs
t_y	Maximum failing test time	SVDT Enabled I_Qx < I_{UC}	450	500	550	µs

Refer to *Section 4.8.13: Silent valve driver test (SVDT).*

3.3.12 V_D measurement

(refer to *Section 4.5.2 VD* for details)

Table 20. V_D measurement electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
V_{Dtol}	V_D measurement accuracy	V_D = 10 V	-	-	10	%
V_{res}	Voltage resolution	-	-	0.1	-	V
t_{int}	Integration Time	V_D = 13.5 V		0.71	-	ms

V_D-Integration time increases linearly with V_D.

Table 21. V_D measurement bit values

SPI - bit	D8	D7	D6	D5	D4	D3	D2	D1	D0
VD-value	16 V	8 V	4 V	2 V	1 V	1/2 V	1/4 V	1/8 V	1/16 V

3.3.13 Rs measurement

(refer to *Section 4.5.2 : RS* for details)

Table 22. R_S measurement electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
$R_{S\_M\_ACC}$	R_S-measurement accuracy	-	-	-	10	%
$R_{S\_M\_RES}$	R_S-measurement resolution	-	-	8.6	-	mΩ

Table 23. Rs SPI bit values

SPI - Bit	D8	D7	D6	D5	D4	D3	D2	D1	D0
R_S-value	4 Ω	2 Ω	1 Ω	1/2 Ω	1/4 Ω	1/8 Ω	1/16 Ω	1/32 Ω	1/64 Ω

Note: R_S-measurement time increases linearly with R_S.

3.3.14 V_FWD measurement

(refer to *Section 4.5.2 : V_FWD* for details)

Table 24. V_FWD measurement electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
V_{FWD_ACC}	V_FWD measurement accuracy	-	-	-	10	%
V_{FWD_RES}	V_FWD measurement resolution	-	-	7.8	-	mV
V_{FWD_MEAS}	Expected measured voltage range	-	0.5	0.7	1.3	V

V_FWD-measurement time increases linearly with V_FWD.

Table 25. V_FWD SPI bit Values

SPI - Bit	D8	D7	D6	D5	D4	D3	D2	D1	D0
V_FWD	2 V	1 V	1/2 V	1/4 V	1/8 V	1/16 V	1/32 V	1/64 V	1/128 V

3.3.15 Internal oscillator

Table 26. Internal oscillator electrical characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
f_{osc}	Oscillator frequency	-	1.4	2.0	2.6	MHz

3.3.16 SPI timing characteristics SPICLK, MISO, MOSI, SPICS

Figure 9. SPI timing characteristics SPICLK, MISO, MOSI, SPICS

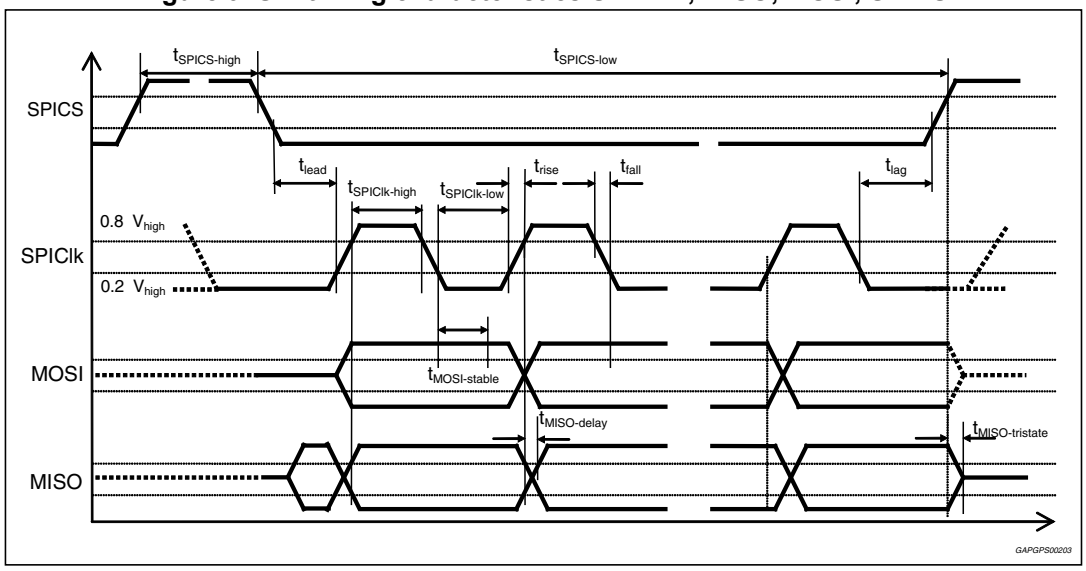


Table 27. SPI timing characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{SPICLK}	SPICLK frequency	C_{load} ≤ 30 pF	0	-	5	MHz
$t_{SPICLK-high}$, $t_{SPICLK-low}$	SPICLK high time / low time	-	68	-	-	ns
t_{lead}	SPICS -> SPICLK delay	-	80	-	-	ns
t_{lag}	SPICLK -> SPICS delay	-	60	-	-	ns
$t_{MOSI-stable}$	MOSI stable	-	68	-	-	ns
t_{rise}/t_{fall}	SPICLK, MOSI rise time / fall time	C_{load} ≤ 150 pF	0	-	100	ns
$t_{MISO-delay}$	SPICLK -> MISO delay	C_{load} ≤ 150 pF	-	-	80	ns
$t_{MISO-rise}$, $t_{MISO-fall}$	MISO rise time / fall time(1)	C_{load} ≤ 15 pF C_{load} ≤ 50 pF C_{load} ≤ 65 pF	0.8 2.5 3.5	2 7 9	7 21 28	ns ns ns
$t_{SPICS-high}$	SPICS high time / low time	C_{load} ≤ 150 pF	150	-	-	ns
t_{MISO_tri}	MISO tri-state	C_{load} ≤ 150 pF	-	-	100	ns

1. guaranteed by design

Note: The MISO pin is tri-stated with a weak pull-up when SPICS is high.

4 Circuit description

The L9374LF is a four channel low side driver with integrated recirculation diodes intended for ABS applications. The device communicates entirely by 16 individual SPI commands. All outputs can be switched or PWMed. Two outputs have the additional capability of providing current regulation

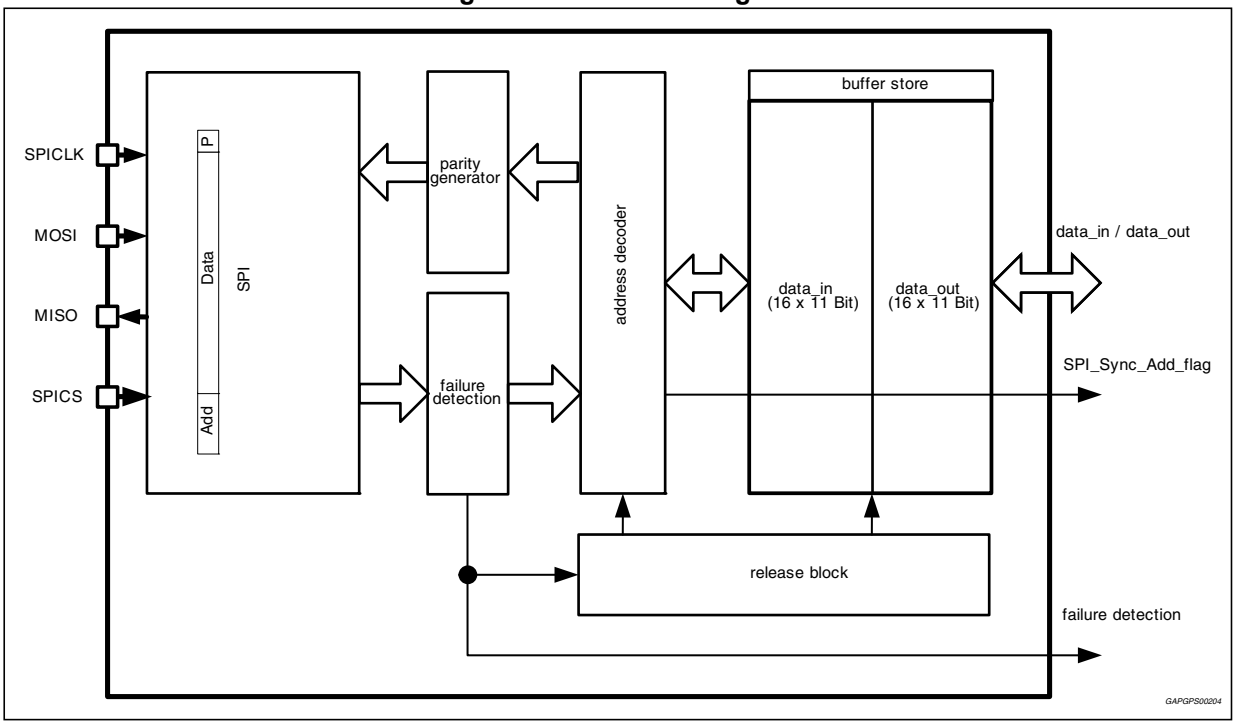
It is possible to program two consecutive PWM duty cycles / Current levels at one time. Individual switched on-times can also be generated.

All outputs have high level diagnostic capabilities. These include off state open load, under current, shorted load, gate voltage monitoring, thermal warning and shutdown flags. Higher level diagnostics include a Silent-Valve-Detection-test (SVDT) to verify load and driver integrity as well as a Built-in-Self-test (BIST) to verify the internal logic integrity. The L9374LF can detect and report a missing recirculation diode, Ground loss, Clock failure, and synchronization failure.

4.1 SPI serial peripheral interface

The L9374LF SPI is a fully bidirectional serial interface configured as a SLAVE for communication between a µC (the MASTER) and the L9374LF. All data management is handled in 16 sets of SPI registers of 16 bits each. There are 16 input or command registers and 16 status registers. All output control including current control and PWM / switching timing is realized internally. The control parameters (Duty Cycle, Duration, and Current regulation) are programmed via serial communication. The 16 status registers provide a high level of diagnostic capability from output status to internal control parameter confirmation.

Figure 10. SPI block diagram



Messages from the master (µC) to the L9374LF is sent over the MOSI (Master out Slave In) pin. Messages from the L9374LF to the master will be sent over the MISO (Master in Slave Out) pin.

The master starts the communication with a '1' → '0' transition on the SPICS pin. After t_{LEAD},(*Table 27.*) the master sends a clock signal to the SPICLK and data to the MOSI pin. The SPICLK pin must be low at the falling edge of SPICS and remain low for t_{LEAD} for correct communication to occur. The SPICS pin must rise after every 16 bits sent.

The MISO pin is tri-stated with an high ohmic pull-up resistor when the SPI chip select (SPICS) pin is held high.

The SPI has the following features:

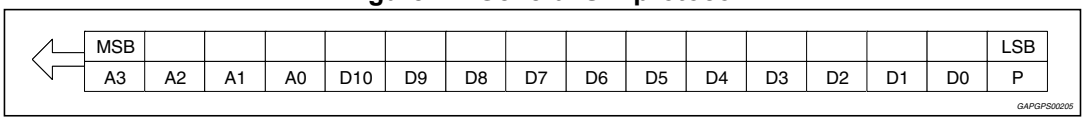
- 4 wire SPI (SPICS, SPICLK, MOSI, MISO)
- Word length of 16-Bits (0..15)
- 4 address and 11 data bits and one parity bit
- 16 receive-buffers (11 bit wide)
- 16 send-buffers (11 bit wide)

4.1.1 General protocol

The protocol has the following structure:

- A parity-bit at the LSB and eleven data bits (bits 1 to 11).
- The four address bits are at the highest position at the transfer (bits 12 - 15).
- SPI communication begins with the MSB.
- High level = '1'
- Low level = '0'

Figure 11. General SPI protocol



- Ax: address bits
- Dx: data bits
- P: parity bit

A message from the L9374LF to the master µC (MISO) contains 4 address bits. These bits are not a copy of the received address from the previous transmission, but are addresses that were decoded from the address decoder. This is done so that the master (µC) has the ability to discern the integrity of the L9374LF address decoder.

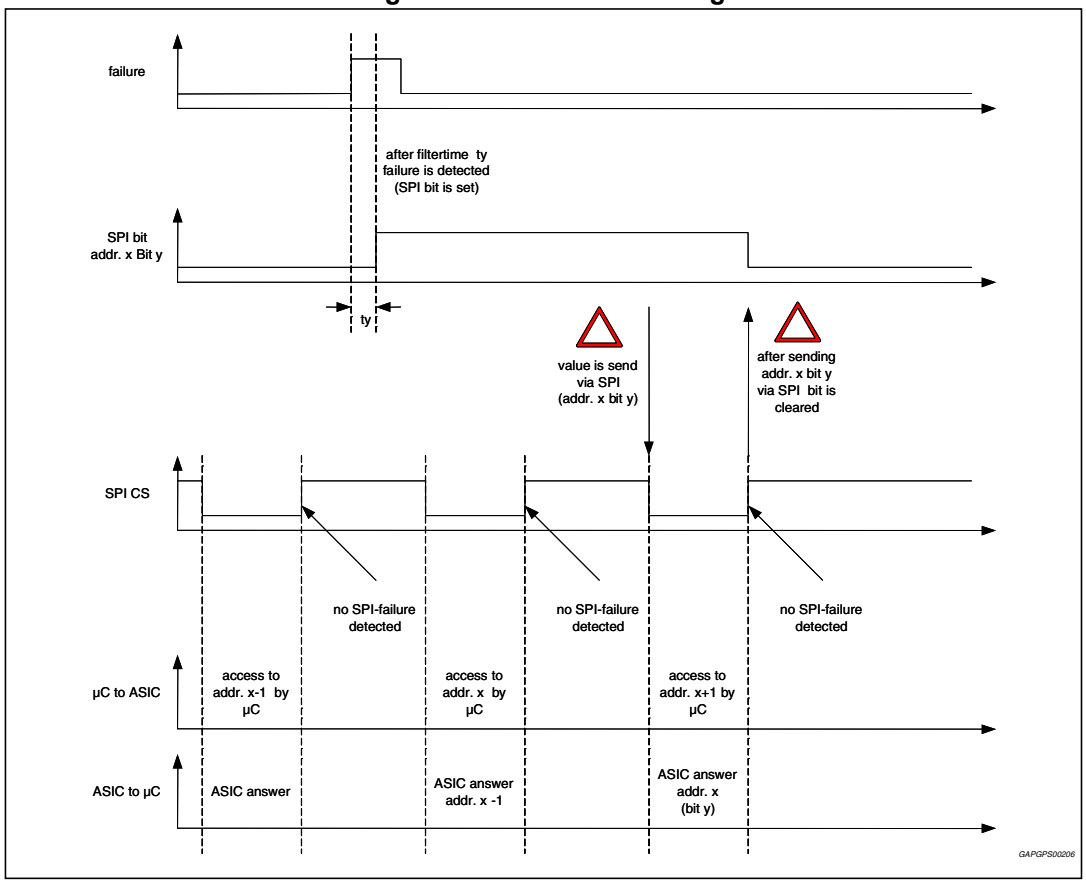
Every time an error bit in one of the SPI registers is set by the L9374LF it will remain set until the corresponding register has been read out via SPI. Once a status register has been read the corresponding register will be reset upon the rising edge of SPICS.

Every SPI communication writes data into a register (read only not possible). Every SPI response is associated with the address of the message sent one communication before.

4.1.2 SPI failure detection

SPI communications sent to the L9374LF that contain errors are ignored. This inaction includes both the commands given and the data retrieved. That is, commands are ignored and the initial state of the output is not changed. Also data registers referenced by the erroneous SPI communication will not be reset.

Figure 12. SPI error handling



Three functions are monitored to discern a correct SPI communication from the master:

1. Correct number of Clock pulses in SPICLK per transfer.
   During each SPICS-low-phase the L9374LF counts the number of positive edges of SPICLK. If this number is unequal to 16 a SPICLK-error is detected.
2. Parity check (odd)
   The L9374LF detects a parity error if the number of ‘1’s within a transfer is even.
3. Data-failure monitoring:
   This bit is set if the master writes inappropriate data to any of the configuration registers (2/14/15).

4.1.3 Data transfer

Upon the completion of each 16 bit SPI command (rising edge of SPICS), data is transferred from the SPI block to the appropriate internal registers. Some internal SPI registers are reset (such as fault bits) once they are accessed.

4.1.4 Address decoder

The address decoder routes incoming data into the appropriate receive buffer and sets up the appropriate send buffer register to transmit information back to the master (MISO) for the subsequent SPI communication.

4.1.5 Parity generator

The parity generator completes the output messages with a parity bit. The number of ‘1’s within an output-transfer has to be odd. Parity is verified prior to the SPICS going high.

4.1.6 Initial MISO information

After initial power on, the first SPI-answer from the L9374LF reflects the Chip-ID information. Typically, the information will appear as follows:

A3	A2	A1	A0	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P
1	0	1	0	0	0	1	1	1	0	0	0	0	1	1	0

This information is unique to this device and reflects specific device information relevant only to ST.

4.1.7 Register map

This is a brief reference to the register locations within the L9374LF. Refer to *Section 5: Programmers guide* for a more detailed description of each register.

Command buffer (data in)

Table 28. Command buffer (data_in)

Address$_{(HEX)}$	Content	Buffer name
0	Sync-trigger, Reset, and Sync values	SYNC_REG
1	STW min and max values	STW_V
2	Configuration register	CONFIG 1
3	Fast Switch ON gate commands	FSON
4	Duration Registers doe Q1 /Q2	Duration Q1/Q2
5	Duration of current 1 Q3 + duration of current 1 Q4	Duration Q3/Q4
6	Duty cycle 1 Q1	DUTY1_Q1
7	Duty cycle 2 Q1	DUTY2_Q1
8	Duty cycle 1 Q2	DUTY1_Q2
9	Duty cycle 2 Q2	DUTY2_Q2
10	Current/duty cycle1 Q3	CUR/DTY1_Q3
11	Current/duty cycle 2 Q3	CUR/DTY2_Q3
12	Current/duty cycle 1 Q4	CUR/DTY1_Q4
13	Current/duty cycle 2 Q4	CUR/DTY2_Q4
14	Current / PWM controller configuration register 2	CONFIG 2
15	Current / PWM controller configuration register 3	CONFIG 3

Status buffer (data out)

Table 29. Status buffer (data_out)

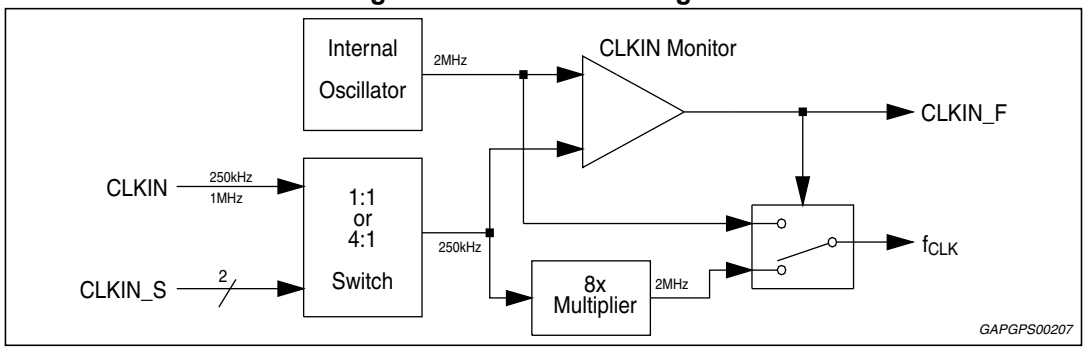
Address$_{(HEX)}$	Content	Buffer name
0	General status	G_STATUS
1	Q1 output status register	STATUS_Q1
2	Q2 output status register	STATUS_Q2
3	Q3 output status register	STATUS_Q3
4	Q4 output status register	STATUS_Q4
5	Voltage of Dx	VD
6	Output-duty Q3	OUT_DUTY_Q3
7	Output-duty Q4	OUT_DUTY_Q4
8	ISAT value for Q3	ISAT_Q3
9	ISAT value for Q4	ISAT_Q4
10	Internal diode Voltage measurement	V_FWD
11	Measurement resistor	RS
12	Current controller status	CC-STATUS
13	Error average Q3	ERRORAVG_Q3
14	Error average Q4	ERRORAVG_Q4
15	Reserved → data ‚000 0000 0000‘	RESERVED

A more detailed explanation about the register settings can be found in section *Section 5: Programmers guide*.

4.2 Clock

The clock controller contains a CLKIN-monitoring function to validate the CLKIN frequency, a clock multiplier to produce an internal 2 MHz clock, and an internal oscillator for monitoring purposes and backup.

Figure 13. Clock block diagram



4.2.1 Clock multiplier

The Clock Multiplier provides a steady 2MHz signal (f_{CLK}) for the internal logic based on the CLKIN signal. The multiplier factor is determined by setting the CLKIN_S bits in the SPI Command register *Configuration register 1 (address 2)*. It is possible to have the wrong CLKIN_S bits set for a specific CLKIN frequency. When this occurs a CLKIN failure (CLKIN_F) is registered.

4.2.2 Internal oscillator

The 2MHz internal oscillator ($f_{osc,}$ *Table 26.*) provides a comparison signal used to validate the incoming CLKIN signal. If the CLKIN signal is determined to be out of range then the internal oscillator is used to provide clock signals internal to the L9374LF. The internal oscillator does not have the accuracy of a proper CLKIN signal. Therefore the diagnostic filter times will reflect the accuracy of this clock for that case.

4.2.3 CLKIN signal monitoring

The CLKIN signal is an external 250 kHz or 1MHz signal from the µC to the L9374LF. This signal is monitored to be within a specified range ($f_{CLKIN\_L} < f_{CLKIN} < f_{CLKIN\_H}$, *Table 17.*). If the value is out of range, then the CLKIN_F (CLKIN failure) bit is set to '1'. If a CLKIN failure (f_{CLK} out of range) is detected, the outputs are disabled and the internal 2MHz oscillator is used as the clock for the internal logic.

Table 30. Clock validation

CLKIN	CLKIN_S 250 kHz / 1 MHz	f_{CLK}	CLKIN_F
250 kHz	250 kHz	2 MHz	0 (no failure)
1 MHz	1 MHz	2 MHz	0 (no failure)
250 kHz	1 MHz	1 MHz	1 (failure)
1 MHz	250 kHz	8 MHz	1 (failure)

4.3 Synchronization controller

Due to the natural SPI communication task time jitter, proper actuation of the outputs requires some level of synchronization. The Synchronization Controller provides synchronized output actuation eliminating SPI task time jitter issues.

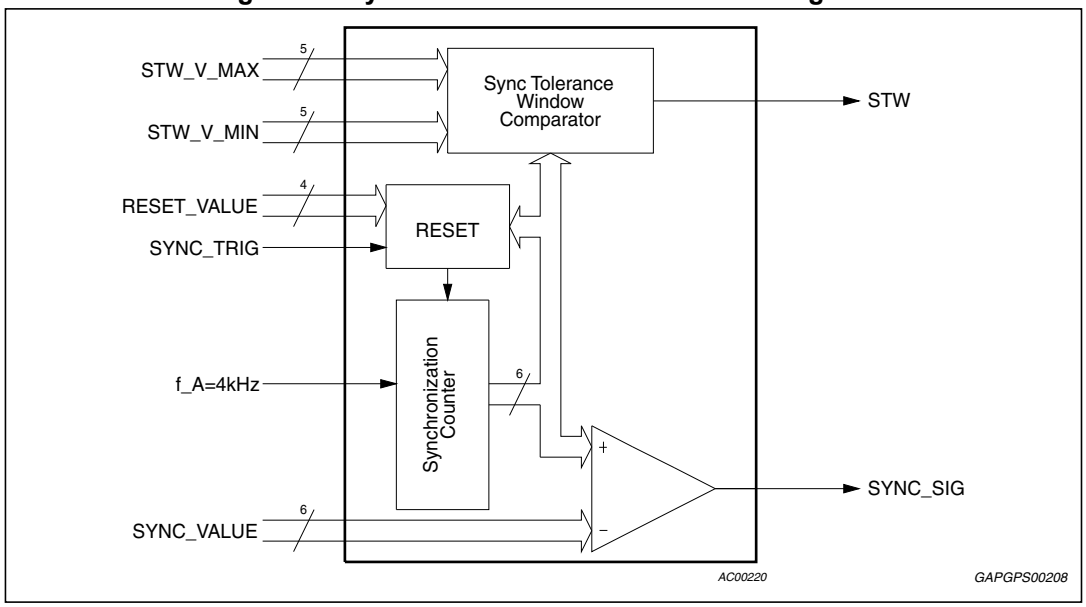
This function forces the outputs to change their commanded state at a specified point in time outside the SPI communication window. This also ensures a more stable SPI communication by minimizing ground fluctuation due to output switching during periods of SPI communications. This delay between the SPI commands and the output actuation is programmed by setting the RESET_VALUE and SYNC_VALUE parameters located in register 0.

4.3.1 Output synchronization

The RESET_VALUE time value is determined by using the typical time between SPI cycles. When programmed properly, the SPI communications occur at or around the RESET_VALUE timing. The Sync Tolerance Window (STW) is an interval of time between RESET_VALUE times where accessing the Sync *Section 5.1.1: Sync + Sync-trigger register (address 0)* during this interval generates a sync failure (SYNC_F). This window is defined by the parameters STW_V_MIN and STW_V_MAX.

The SYNC_VALUE is a programmed delay after the RESET_VALUE when the output transitions occur. This delay is typically set as half of the RESET_VALUE. This sets the output transitions furthest from each SPI cycle and during the STW.

Figure 14. Synchronization controller block diagram



Inputs

The synchronization controller receives the following input signals:

- f_A = 4 kHz for internal clocking.
- SYNC_TRIG =”1” initiates the synchronization timing with that SPI event.
- SPI synchronization values (SYNC_VALUE, RESET_VALUE, STW_V_MIN; STW_V_MAX) provide the parameters that allow for output synchronization.

Outputs

The synchronization controller provides the following output signals:

- The STW signal is used in conjunction with accessing address 0 to notify the master that the SPI cycles are within the programmed exclusionary window (SYNC_F=1).
- The SYNC_SIG initiates the actuation of the new output commands.

The synchronization counter increases its value with every period of f_A. When the value of the counter equals the SYNC_VALUE a synchronization signal (SYNC_SIG) is generated (SYNC_SIG=’1’).

The synchronization counter continually counts to the RESET_VALUE and resets unless a SYNC_TRIG command is sent. If a SYNC_TRIG command is sent then the counter resets immediately. Upon resetting the SYNC_TRIG and STW signals are reset (SYNC_SIG = STW =’0’).

Normal sequence

When stepping through a normal sequence of events the following occurs:

- At a SYNC_TRIG (SYNC_TRIG='1') command the synchronization counter, STW and SYNC_SIG flags are reset (STW='0', SYNC_SIG='0')
- The counter counts up at a rate defined by f_A = 4 kHz.
- When the counter value reaches STW_V_MIN the STW flag is set (STW='1')
- When the counter value reaches SYNC_VALUE the SYNC_TRIG flag is set (SYNC_TRIG='1') which activates the most recent output commands.
- When the counter value reaches the STW_V_MAX value the STW flag is reset (STW='0')
- When the counter value is equal to the RESET_VALUE the counter is reset and the output signal sync_signal is reset (SYNC_SIG='0')

Disallowed programming states

Erroneous programming results in the STW flag being set '1'

- If the STW_V_MIN value is higher than or equal to STW_V_MAX value the STW flag is set (STW = 1)
- If the STW_V_MAX value is higher or equal to the RESET_VALUE value the STW flag is set (STW = 1)

Synchronization failure

Sync failure detects a timing error in the output command synchronization. The master µC programs a timing window (STW) where accessing to the Status Register address 0 is not allowed.If there is an access to the Status Register address 0 when the STW flag is set then a sync-failure is generated (SYNC_F = 1). Also, a SYNC_F will be detected if there is no SPI traffic at all between two SYNC_SIG events. This status will be read out on the subsequent SPI transfer.

Without a SYNC_SIG or at sync-failure there is no effect for the actuation and setpoints

Synchronization controller programming

It is necessary to write into two registers (Command Register addresses 0 and 1, sections *5.1.1* and *5.1.2*) to program the Synchronization Controller. The SYNC_VALUE, the RESET_VALUE and the SYNC_TRIG values are programmed through address 0. The SYNC_TRIG is written to once to initialize the counter. Once initialized the SYNC_TRIG bit is reset by the controller. Subsequent SPI transfers the SYNC_TRIG bit should not be set to avoid re-initializing the sync counter. There is no influence on the sync counter if the SYNC_TRIG is not set. Occasionally, the sync counter may need re-initializing depending on the timing between the RESET_VALUE and the µC loop time. The RESET_VALUE is incremented by 1ms intervals. The SYNC_VALUE is incremented by 250µs intervals.

The STW_V_MIN and STW_V_MAX values are programmed via register 1 (*Section 5.1.2*). Their interval length is dependant on the RESET_VALUE MSB (address '0', bit D9)

Table 31. Sync. tolerance window interval length

RESET_VALUE (add.0, bit D9)	RESET_VALUE Duration	Sync tolerance window interval
0	<8ms	250 µs/bit
1	≥8ms	500 µs/bit

Example

Example for a 5 ms cycle time, 2.5 ms SYNC_VALUE-, STW of +1.75 ms/-1.25 ms:

- Cycle time:
  - For programming the cycle time the master has to write the RESET_VALUE (4 bit) via SPI. One bit has the resolution of 4/f_A = 1 ms.
  - RESET_VALUE: 5 ms / 1 ms = 5 → $0101_{(2)}$
- SYNC_VALUE:
  - For programming the sync-signal the master has to write the SYNC_VALUE (6 bit). The LSB has the resolution of 250 µs.
  - SYNC_VALUE: 2.5 ms / 250 µs = 10 → $00\ 1010_{(2)}$
- Sync tolerance window:
  - For programming the STW the master must write min and max values (2 x 5 bit):

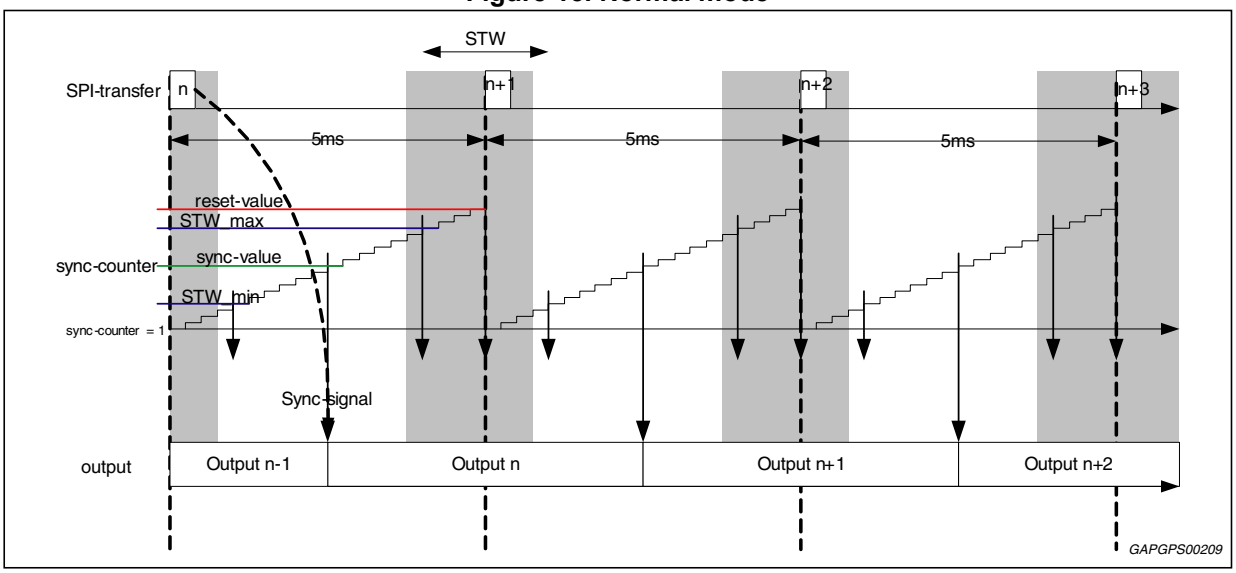
    STW_V_MIN: 0.75 ms

    STW_V_MAX: 3.75 ms

    STW_V_MIN: 0.75 ms / 250 µs + 1 = 4→ $0\ 0100_{(2)}$

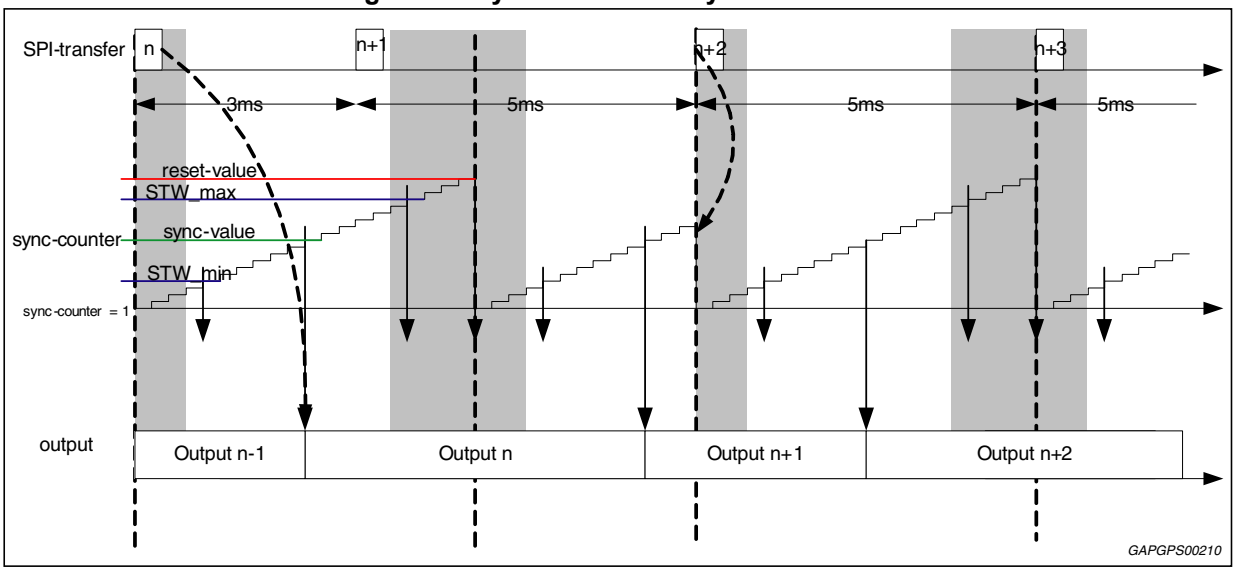
    STW_V_MAX: 3.75 ms / 250 µs + 1 = 16→ $1\ 0000_{(2)}$

Figure 15. Normal mode



SPI transfer means transfer of all send and receive registers (0 through 15).

Figure 16. Sync-failure + re-synchronization

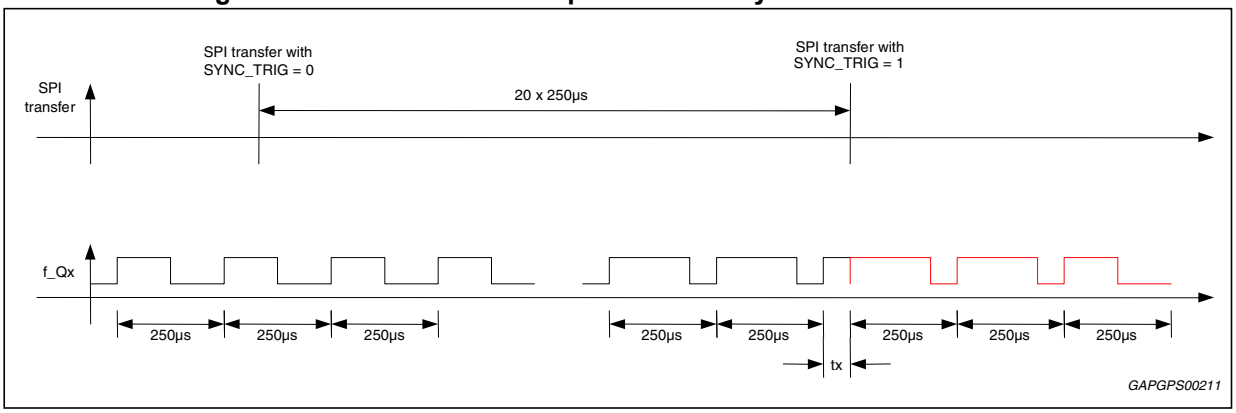


Re-synchronizing

The master sets the SYNC_TRIG bit to ‘1’ (section *5.1.1*) to re-initialize the sync counter. This re-synchronizes the L9374LF synchronization controller to the master. When this bit is set three counters are reset: the PWM counter (output frequency and duty cycle), synchronization counter and the duration counter. The SYNC_TRIG bit is reset (set to ‘0’) by the L9374LF upon re-synchronization.

The picture below shows the behavior of the output when the synchronization is done. The time tx is anything lower than 250 µs.

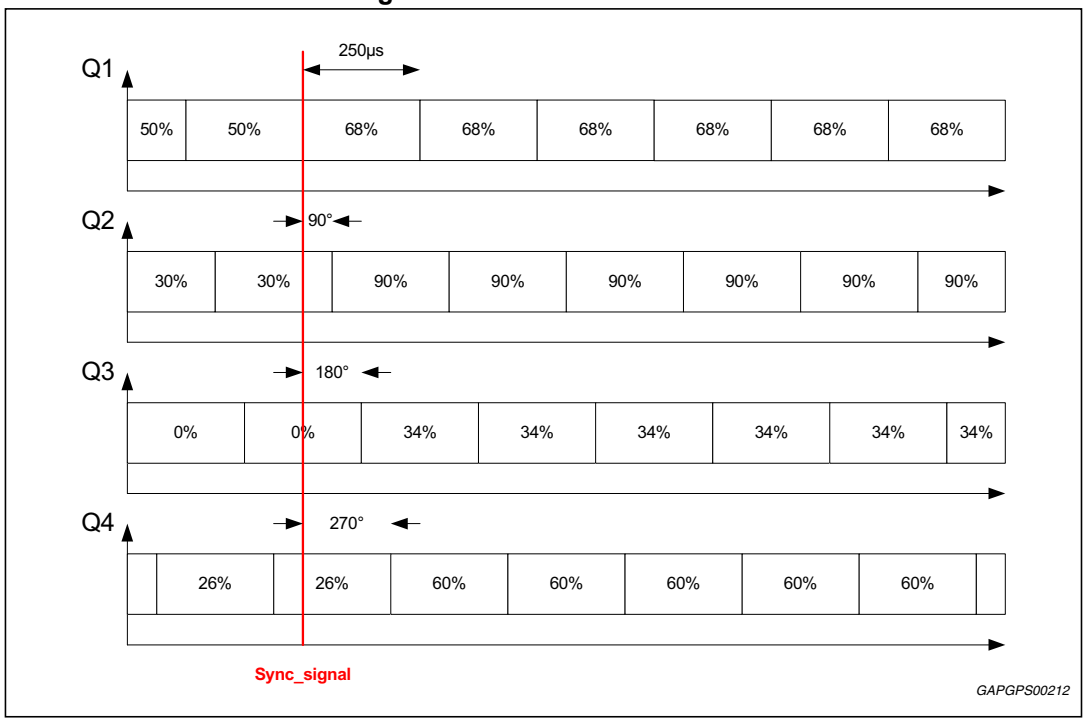
Figure 17. Behavior of the output when the synchronization is done



4.3.2 Time shift between output actuation

The actuations of the outputs are time shifted by 90° (typ. 62.5 µs) to offset their effect on the supply during switching. This balances the incremental switching current and reduces the EME generated by the switching of these channels. The new duty cycle or target current also becomes valid with this 90 degree time shift after the SYNC_SIG.

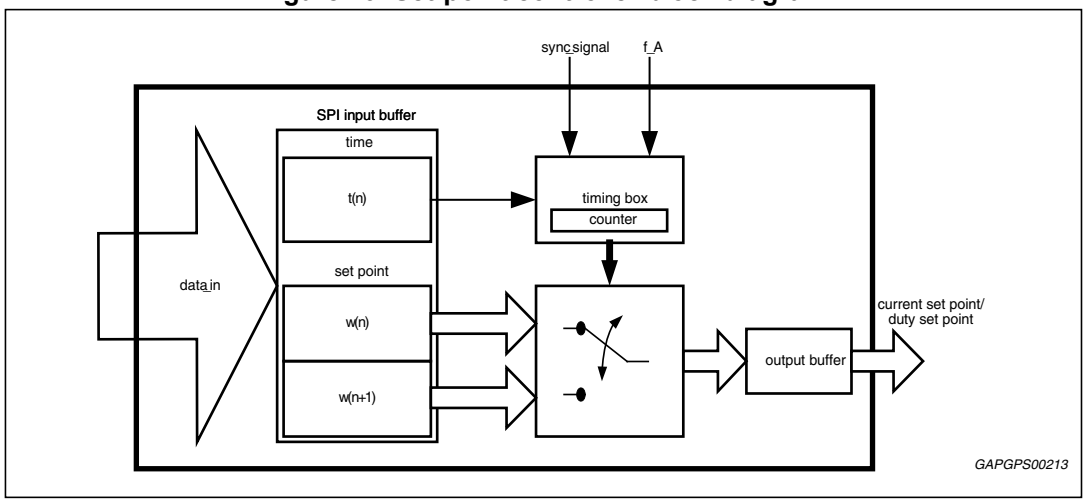
Figure 18. Channels time shift



4.4 Set-point controller

The set point controller generates a PWM duty cycle based on a duty cycle value or a regulated current value from the SPI command registers for each output. This circuit is designed to generate two different PWM duty cycle / current regulation values for each output per SPI cycle. This translates to a duty cycle/current level [w(n)] for a duration [t(n)] and then a second duty cycle/current level [w(n+1)] until otherwise commanded for each output per SPI cycle. Depending on what is driving this controller (Direct SPI command (in the form of a duty cycle value) or Current Controller) the end result is either a fixed commanded PWM duty cycle or a regulated current.

Figure 19. Set-point controller block diagram



The set point controller receives the following input information:

- Synchronization-signal (SYNC_SIG)
- Frequency of the PWM-generator (f_A; duty 50 %)
- Set Point 1 (Duty cycle/current 1) = w(n)(9 bits)
- Set Point 2 (Duty cycle/current 2) = w(n+1)(9 bits)
- Duration (duration of Duty cycle/current 1) = t(n)(5 bits)

The Duty cycle/current set point value is the only output signal.

The timer commands the change between w(n) and w(n+1) to the Duty cycle/current set point according to the programmed timing value t(n). The counter in the timing box is controlled by f_A and bit D9 of address 0 (see *Table 33.*). If the value of the counter is lower than t(n) the Duty Cycle/current set point is set to w(n). If the value is equal or higher the Duty Cycle/current set point is set to w(n+1).

Table 32. Example of PWM duration timing, t(n)

Duration value (5 Bit)	Add. 0, bit D9	on-time (ms)
$00000_{(2)}$	X	0 ms (off)
$11111_{(2)}$	0	7.75 ms
$01101_{(2)}$	0	3.25 ms
$11111_{(2)}$	1	15.5 ms
$01101_{(2)}$	1	6.5 ms

Note that the RESET_VALUE MSB (bit 9 of address 0) affects the timer duration. With the MSB set the timer values double. This means if the SPI cycle time is equal or higher than 8 ms ($>100_{(H)}$) the resolution of the duration t(n) is 500 µs per LSB instead of 250 µs.

Table 33. Timer t(n) resolution versus RESET_VALUE MSB

RESET_VALUE (add.0, bit D9)	RESET_VALUE duration	Resolution of timer duration
0	<8ms	250 µs
1	≥8ms	500 µs

The timer counter is reset by the SYNC_SIG.

All buffers and the timer counter are reset by:

- A CLKIN failure detection (CLKIN_F = ‘1’)
- A re-synchronization command (SYNC_TRIG = ‘1’)

The value range (externally programmed):

- w(n): 9 Bit
- w(n+1): 9 Bit
- t(n): 5 Bit

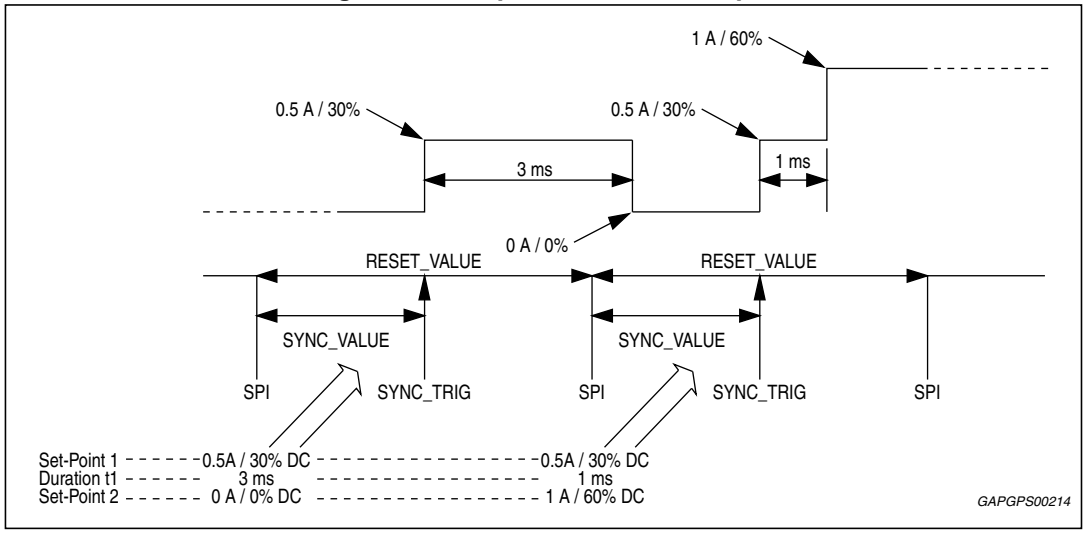
Example of set-point control

Below is an example of programming two sets of Set-Points sequentially. After programming the parameters that govern the synchronization (RESET_VALUE, SYNC_VALUE and the

SWT values) the parameters Set-Point 1 (DUTY1 or CUR/DTY1), Set-Point 2 (DUTY2 or CUR/DTY2) and duration t1 (D_Qx) are programmed (for programming instructions see section *5.1.5: Duration registers (address 4 and 5)*).

Generically, after the SYNC_TRIG the Set-Point 1 is valid for t1 ms. After t1 ms the set-point controller switches to Set-Point 2 until the next SYNC_TRIG event.

Figure 20. Set-point control example



In this example the RESET_VALUE (and therefore the SPI transfer loop time) is set to 5ms and the SYNC_VALUE is set to 2.5 ms. This sets the SYNC_TRIG at 2.5 ms after each SPI transfer. At SYNC_TRIG, the new information received at the previous SPI transfer is incorporated into the Set-Point Controller.

4.5 Current controller

Two outputs (Q3 & Q4) are equipped with a current controller. The current controller converts the Set-Point controller output (Current Set Point) into a current level regulated duty cycle command using a sophisticated algorithm incorporating Load resistance supply voltage, and recirculation path variances.

The current controller output duty cycle information is calculated using a dedicated load model in standard Arithmetic Logic Unit (ALU). This model includes the supply voltage, the recirculation path as well as the load resistance. The load resistance value is programmable via SPI while the recirculation path and the load supply voltage parameters are measured by the L9374LF. These measured values are readable via SPI as well.

4.5.1 Load resistance error integration phase

The value of the programmed Load is corrected during the valve actuation. This correction is called the Error Integration Phase and the resulting value (ISAT_Qx,) is accessible via SPI (Status registers 8 and 9, *Section 5.2.5*). ISAT_Qx is an internal value of the current controller. In an ideal system (without any system tolerances) the first approximation is determined y the equation:

$$ISAT \approx \frac{RL\_real}{RL\_SPI} - 1$$

$RL\_real \approx RL\_SPI \cdot (1 + ISAT)$

ISAT is the relative error of the SPI-Value RL_SPI to the real load RL_real (within an ideal system).

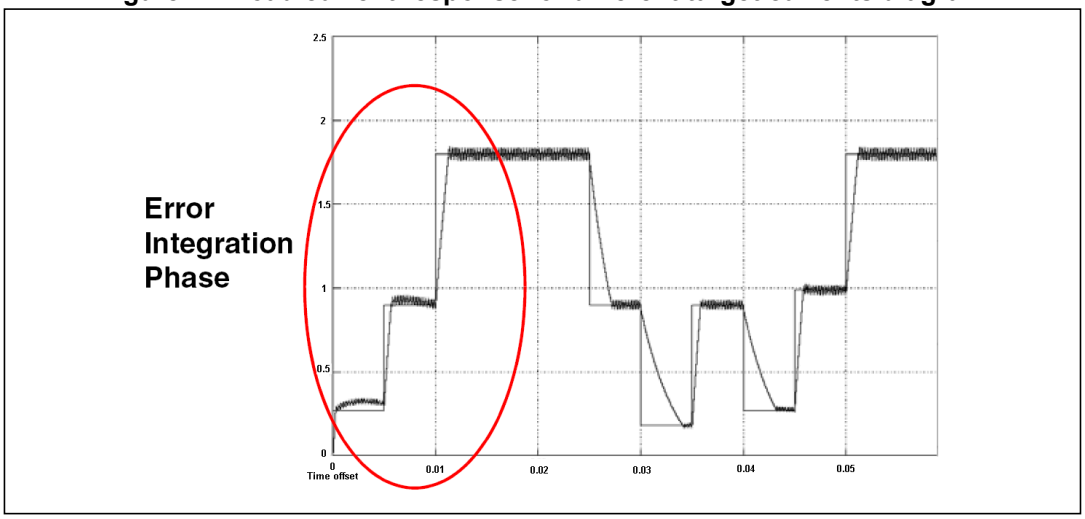
ISAT is a twos complement. The range value is {-1 … +(1-LSB)} and

$$\left|LSB_{(ISAT)}\right| = \frac{1}{512}$$

With this algorithm a fast controller dynamic can be achieved. *Figure 21* shows the load current response for different target currents. The ISAT_Qx value integration is disabled for commanded target current values less than $29_{(DEC)}$. This corresponds to a target current of:

$$1.8A \times \frac{29}{512} = 102mA$$

Figure 21. Load current response for different target currents diagram



Starting at time zero a load error is corrected by modifying the programmed load resistor value with an integral correction factor I_{SAT}. This integration function is valid for target currents higher than 110mA. If the ISAT value is once corrected in the system the load model will respect the required precision immediately if the target current is reached in the load. To avoid a long error integration phase during actuation of the ABS system it is recommended that the current controlled outputs (Q3 & Q4) be activated periodically. This will allow the L9374LF to adjust the I_{SAT} parameter for any possible load resistance changes due to temperature.

The integral correction factor (ISAT) is remembered and potentially modified at every load actuation. It can be reset by changing RL or resetting the Current controller (see *Section 5.1.9*). If reset, the load resistance error correction will be recalculated upon the next output actuation.

4.5.2 Analog signal measure blocks

All internal analog measurements are converted into digital values for use internal to the L9374LF. These values are accessible via SPI. The supply of the load, an equivalent measured resistor, as well as an equivalent recirculation diode forward voltage are measured with the same analog to digital converter sequentially.

- VD, Register 5, bits D0-D8
- RS, Register 11, bits D0-D8
- V_FWD, Register 10, bits D0-D8

VD

The VD is measured by the L9374LF as the voltage present at pin D13.The value for VD can be read in the SPI register 5 (refer to *3.3.12: VD measurement* and *5.2.3: VD (address 5)*).

RS

An equivalent sense resistor is measured internal to the L9374LF. The digital value is stored in SPI-register 11. The value is corresponding to the measurement resistor which is used for the current controller. The digital value is multiplied with the factor of 1.8 (refer to *3.3.13: Rs measurement* and *5.2.7: Sense resistor measurement (Rs) (address 11)*.

This means:

$Rs_{(SPI)} = 1.8 \cdot Rs_{measured}$

To get the right value of Rs it is necessary to divide the SPI-value by 1.8.

The resolution of the LSB is 8.7mΩ (typ.) and the parameter range is:

Condition	Rs-value (Ω) (after division by 1.8)
Min	0.62
Typ	1.00 (TK = 1.57 mV/K)
Max	1.58

V_FWD

An internal reference diode forward voltage is measured using a fixed bias current. This corresponds to the forward voltage drop across one of the current controller freewheeling diodes. The digital value is stored in SPI Status register 10 (refer to *3.3.14: V_FWD measurement* and *5.2.6: Reference diode voltage measurement (V_FWD) (address 10)*).

Load current measurements

The load current is measured in both the on and the off state of the output. This measured current is subtracted from the target current which is set by a digital to analog converter. The load current difference is converted into a digital signal for each output. This digital signal is called error average. The error average is an internal value of the current controller. The error average is the integral of the difference between the target current and real current within a PWM period (250 µs).

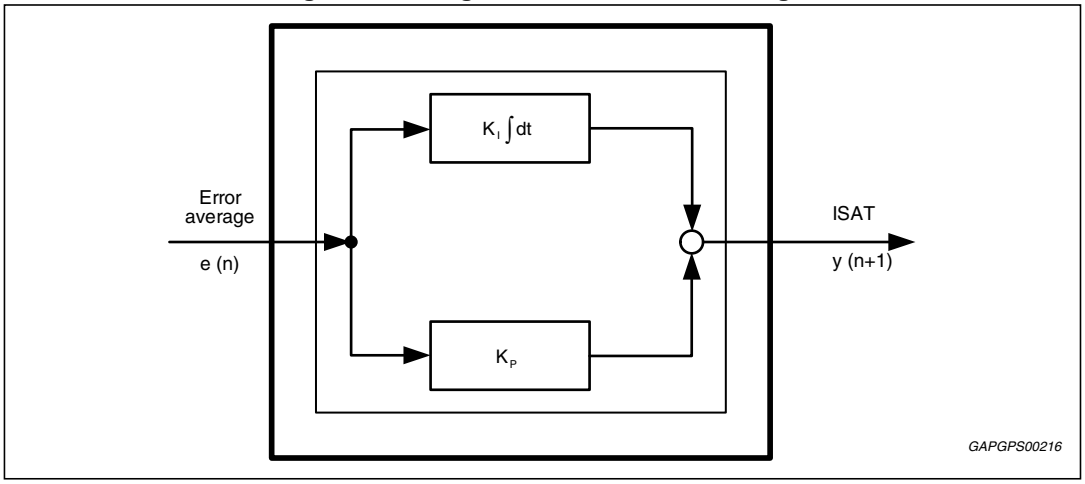
$$ERRORAVG\_Qx = \frac{1}{T}\int_{T}(I_{target} - I_{real})dt$$

The error average is a twos complement number. The range value is {-[value] … +([value]-LSB)} and

$$|LSB_{(erroraverage)}| = 3.6mA$$

This value is available in the SPI Status registers 13 and 14 (refer to *5.2.9: Error average (address 13 + 14)*).

Figure 22. Integration of the error average



The current controller calculates the correction factor ISAT out of the error average within an output period (1/f_A). During a period (n) it calculates the control variable y(n) with the current deviation e(n). At the next period n+1 the control variable y(n) is used. The value ISAT is always stable if the load resistor value is stable. More details about the usage of ISAT you will find in the following chapters.

4.5.3 Duty cycle calculation in the ALU

The ALU is shared between outputs 3 and 4 in the L9374LF. The following equation is used by the ALU to provide the output PWM duty cycle information to the Duty cycle Generator.

$$dc = \frac{V_{DR} + I_{TARGET} \cdot R_s}{V_{DR} + V_{BAT} + I_{TARGET} \cdot (R_s - R_{DS(on)})} + \frac{I_{TARGET} \cdot R_{LSPI}}{V_{DR} + V_{BAT} + I_{TARGET} \cdot (R_s - R_{DS(on)})} \cdot (I_{SAT} + 1)$$

Where:

V_{DR}: Forward voltage of the recirculation diode (measured value stored in register V_FWD_Qx)

I_{TARGET}: Value programmed by the SPI and provided by the Set Point Unit

R_S: Sense resistor value (measured value stored in register RS)

R_{LSPI}: Value given by the SPI

V_{BAT}: Supply voltage of the load (measured on pin D1/3 stored in register VD)

$R_{DS(on)}$: fixed value of 500mOhm temperature coefficient is not respected

I_{SAT}: Current Controller correction factor

4.5.4 Current controller diagnostic performance

The maximum output value from the current controller is 1FF. This values is only reached if the measured current does not reach the commanded current. If this maximum value extends for more than t_{CNR} (8ms typ, *Table 18.*) the Current Not Reachable flag (CNRx, *5.2.4*) is set. The PWM controller contains the check for this condition (for details see section *4.6.1: Current not reachable detection(Q3 and Q4 only):*).

A set CNRx flag indicates that the load regulation is out of control and resets the ISAT value. This forces the ALU to re-learn a new ISAT value returning the system to a stable dynamic performance.

The ISAT register can be monitored by the master µC to determine if it is on the positive or negative limit. This will indicate if the current controller is out of range and that the current precision can not be assured.

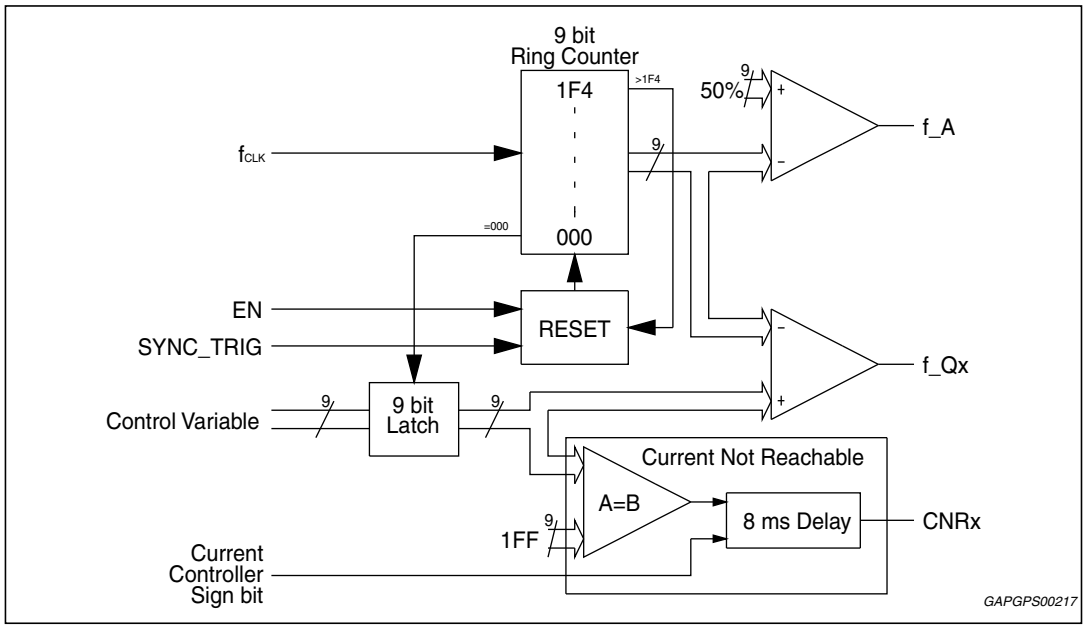
4.6 PWM generator

The PWM Generator converts a Duty Cycle Set Point value into a PWM signal for each Output Driver. The duty cycle setpoint can be derived from either a direct SPI command (through the Set-Point Controller directly) or through the Current Controller.

The PWM-generator (*Figure 23*) provides a 4 kHz PWM duty cycle (f_Qx) depending on the value of the 9 bit control variable. A 9-Bit ring counter counts with a frequency of f_{CLK} (2 MHz). The ring counter output is compared to the control variable. If the value of the counter is lower than the control variable the output f_Qx is high turning on the output Qx. If the value of the counter is equal or higher to the output f_Qx is low turning off the output Qx.

The counter can be reset by either a counter overflow at '$1F4_{(Hex)}$' (→ $500_{(10)}$), or by a SYNC_TRIG command. The control variable value is changed only when the counter passes through zero.

Figure 23. PWM control block diagram



4.6.1 Current not reachable detection(Q3 and Q4 only):

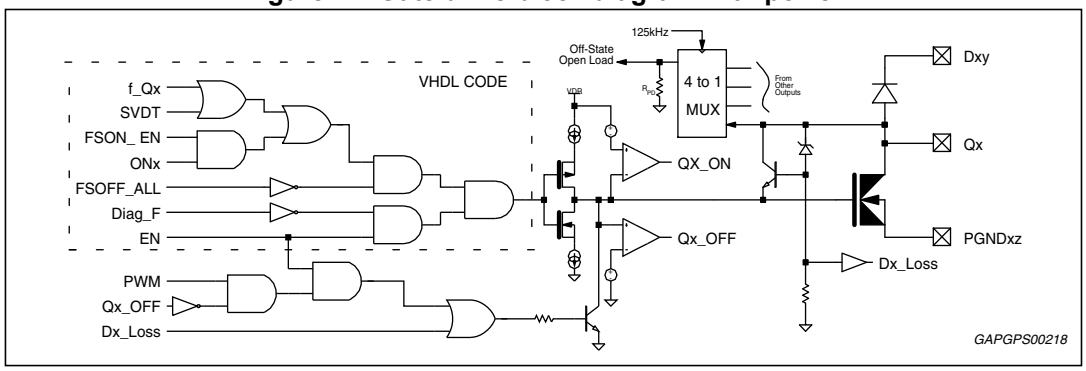
The current not reachable bit is set (CNRx = 1, see section *5.2.4*) when the current controller control variable is set to $1FF_{(Hex)}$ for more than t_{CURR_F} (8ms typ, *Table 18*). This indicates that the current requested has not been attained for that duration. The CNRx bit is also set when the current measurement sign bit is set to 1 for more than t_{CURR_F} (8ms typ, *Table 18*).

In both cases a failure is indicated via SPI (and the ISAT parameter is reset).

4.7 Output driver

The output driver controls the gate of the low side power DMOS as well as provides specific diagnostic information to the SPI diagnostic registers. There are several signals that control the actuation of the output power DMOS. In normal operation the typical input is the f_Qx from the PWM generator. Other inputs that can turn on the output are the silent valve driver test (SVDT) and the Fast Switch on circuitry. Inputs that can disable the outputs are the fast switch off command, device enable, and certain failure detections that can potentially cause catastrophic damage if the output is left on.

Figure 24. Gate drive block diagram with power



4.7.1 Input controls

The output driver control circuit includes the logical combination of the following signals:

- PWM Generator output signal: (f_Qx)
- Silent Valve Driver Test signal (SVDT)
- Device Enable (EN)
- Specific Diagnostic failure indications such as PGND loss, overload, over temperature (Diag_F).
- Fast Switch off for all outputs: (FSOFF_ALL)
- Fast Switch on Enable: (FSON_EN)
- Direct SPI driven output switching through the Fast Switch On command ($ON_{X)}$

In normal operation, the signals EN = ‘1’, FSOFF_ALL = ‘0’, Diag_F = ‘0’, allow the gate to be driven by the PWM Generator signal (f_Qx). PWM Generator signal can override the SVDT input if actuation is commanded during an SVDT.

The signals Diag_F=’0’, EN=’0’ and FSOFF_ALL=’1’ by-pass all other inputs and turn off the output immediately. The Diag_F flag is set to ‘1’ at the detection of PGND loss, overload and

over-temperature disabling the affected output. Hardware Enable (EN) is an external pin and is controlled by the μC directly. FSOFF_ALL is a SPI command that provides a method to shut down all outputs in one SPI command.

4.7.2 Diagnostics

Output stage diagnostics provide fault feedback information for the SPI status registers.

Gate monitoring

Qx_ON and Qx_OFF provide Gate voltage status history information. If the output DMOS Gate voltage is above the Qx_ON threshold at any point between two SPI cycles the Qx_ON output will latch on (‘1’) the SPI bit associated with that signal (bit 6 of status registers 1 - 4). If the output DMOS Gate is below the Qx_OFF threshold at any point between two SPI cycles the Qx_OFF output will latch on (‘1’) the appropriate SPI bit associated with that signal (bit 7 of status of status registers 1 - 4). If an output is PWMmed both Qx_ON and Qx_OFF will return a ‘1’ when read by the SPI. Upon reading status registers 1 through 4 the Qx_ON and Qx_OFF bits are reset to ‘0’.

Conversely if the Gate voltage remains above or below the thresholds mentioned the status bits Qx_ON or Qx_OFF will indicate only one state was present. At no time will both bit not be set.

Table 34. Qx_ON and Qx_OFF provide gate voltage status history information

Condition	QX_ON	QX_OFF
duty: 100%	1	0
duty: 0%	0	1
duty: 0% < dc <100%	1	1
defect	0	0

Freewheeling diode loss detection

Dx_Loss transmits to the SPI register latch a ‘1’ whenever the output protection clamping structure is used. This notifies the SPI that the freewheeling diode, Dx, was not in the circuit.

According *Figure 23* the Device Enable has a direct link to a separate discharge path on the power gate. Only the high voltage clamp (Dx_loss) gets a higher priority, to protect the DMOS from high voltage damage if the freewheeling diode is “lost”.

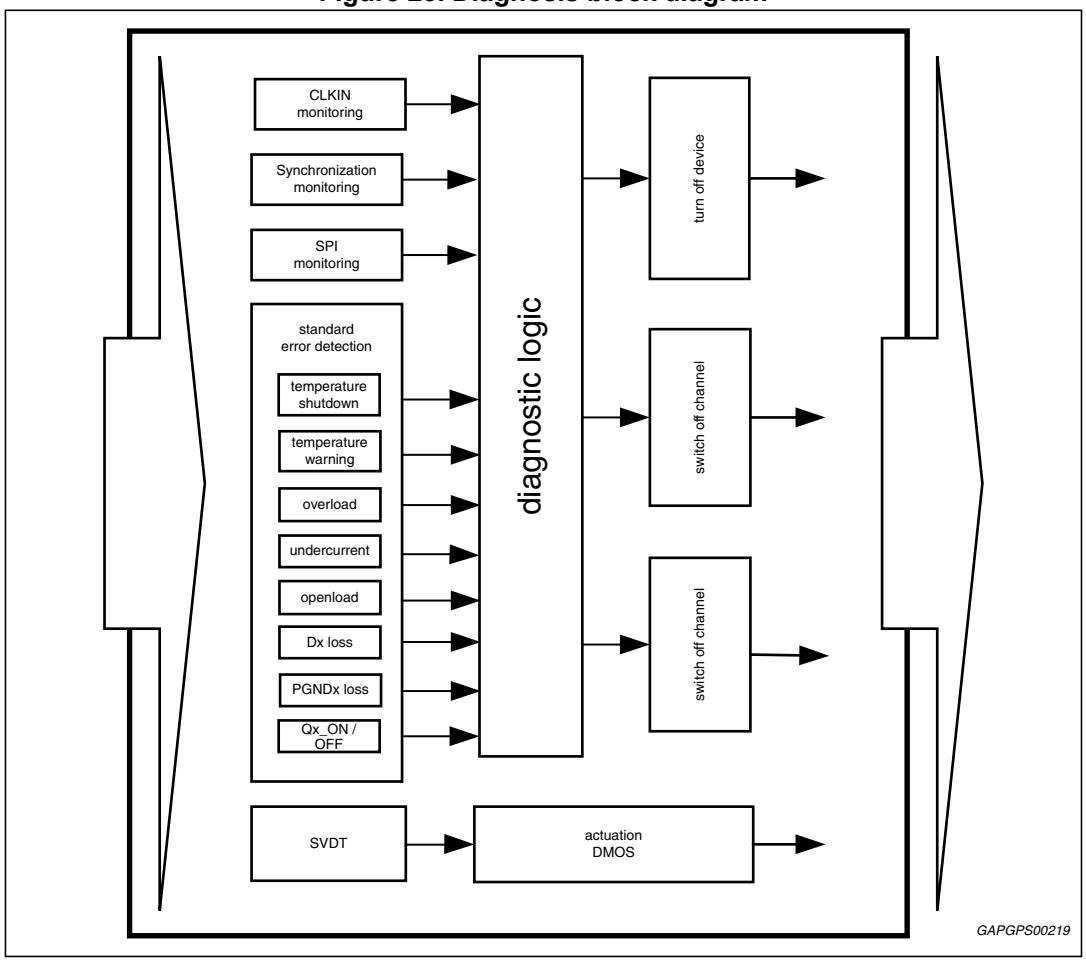
Table 35. Output driver possible input configuration

FSOFF_ALL	FSON_EN	ON_X	Setpoints	Output Qx (0=off, 1=on)	Remark
10	x	x	Q = on / PWM	0	like EN pin
10	x	x	Q = off	0	like EN pin
01	0	x	Q = on / PWM	1 or PWM	-
01	0	x	Q = off	0	-
01	x	0	Q = on / PWM	1 or PWM	-
01	x	0	Q = off	0	-
01	1	1	Q = on / PWM	1	Channel switched on without a sync-signal
01	1	1	Q = off	1	Channel switched on without a sync-signal

4.8 Diagnostics

There is a large amount of diagnostic functions in the L9374LF. These functions are designed to verify internal as well as external conditions to the L9374LF. In so doing virtually every function is checked for proper operation. All of the diagnostic results are read by the master µC via SPI commands.

Figure 25. Diagnosis block diagram



4.8.1 Undercurrent / openload

Undercurrent can be detected if the current through the load in on-state is below the undercurrent threshold (I_{UC}, *Table 15*) for longer than the filter time (t_{UC}, *Table 18*). The filter is active in that a counter counts up when the undercurrent is detected (the device is on AND load current below I_{UC}) and counts down when undercurrent is not detected (either the device is off OR the current is above I_{UC}). Once undercurrent is detected the SPI fault bit is reset when the counter reaches 0.

This bit is not latched unless undercurrent is detected during the SVDT test.

Figure 26. Diagram under current

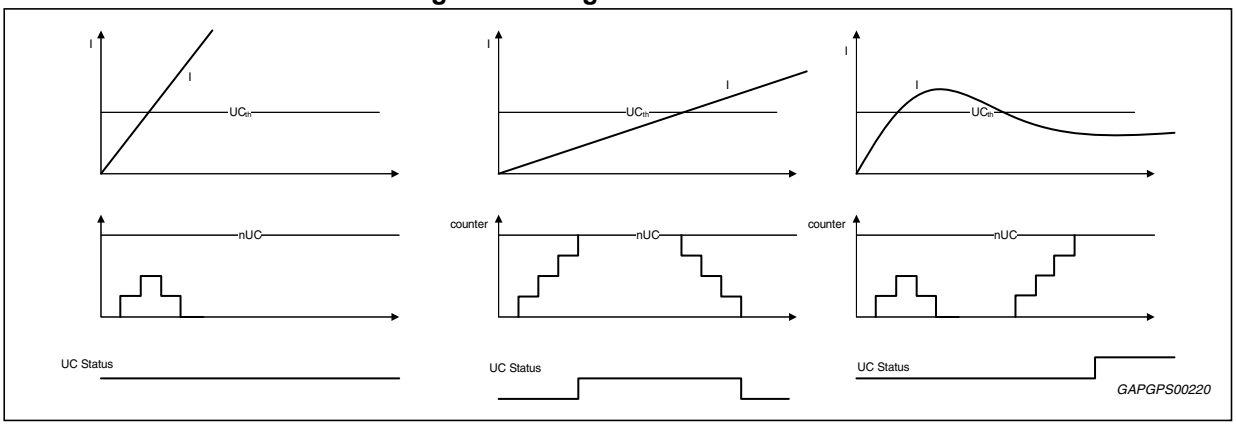
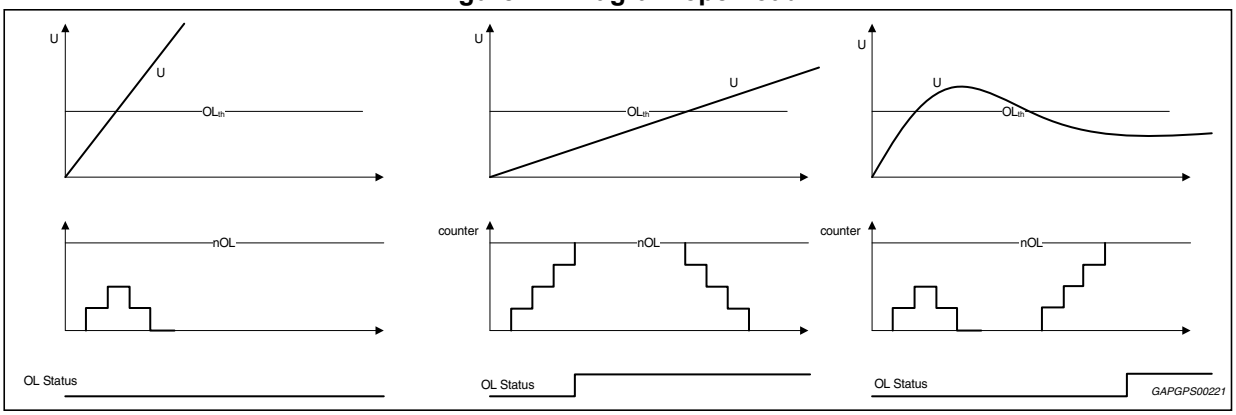


Figure 27. Diagram openload



4.8.2 Openload

Openload detection is done in the off-state through a multiplexed pull-down resistor, R_{PD} (see *Figure 4*). R_{PD} is multiplexed onto each output node sequentially at a fixed 125kHz rate. The output voltage is measured while R_{PD} is connected to the output. Voltages below V_{OL} (*Table 15*) indicate an off-state Open load condition. Multiplexing R_{PD} reduces the overall “leakage” current while providing a substantial pull-down current to verify open load status. There is a counter that “debounces” the open load detection similar to the undercurrent filter counter. Open load is reported in the SPI status registers (bit D0 of registers 1 - 4, *5.2.2: Output status Q1... Q4 (address 1 to 4)*) and is cleared once read.

4.8.3 Overload

If the measured load current is higher than the overcurrent threshold (I_{OCx}, *Table 15*) a failure is detected. The overcurrent detection is measured in on state only. This failure is filtered for t_{OL} (20µs typ., *Table 18*). After t_{OL} the output is shut down immediately and all of the set point and control variables are set to zero. This disables the output from further actuation until the appropriate status registers are read and cleared (refer to *5.2.2*). Once the appropriate SPI status registers are read the offending output(s) are released to be driven again. This failure detection is used for all outputs.

The overcurrent bit is latched upon an overcurrent detection and reset after reading the corresponding SPI register.

Outputs Q1 and Q2 have a selectable overcurrent threshold. These currents are individually selectable as well. (see *Table 15* also *5.1.8: Configuration register 2 - current control / over-voltage threshold (address 14)*)

This failure detection is also used during SVDT (see *4.8.13: Silent valve driver test (SVDT)*).

4.8.4 Thermal warning and thermal shutdown

The L9374LF is equipped with a two stage thermal protection system. This system provides for an early thermal warning and a thermal overload shutdown protection. With thermal warning some countermeasures can be realized by the Master µC to potentially prevent thermal shutdown. The temperature for each output is only measured when the output is on.

Temperature warning has the same functionality as over-temperature. The only differences are:

- The threshold is 20°C below over-temperature.
- The Output is not shut down.
- The SPI-Bit shows the actual status at the time it is accessed.

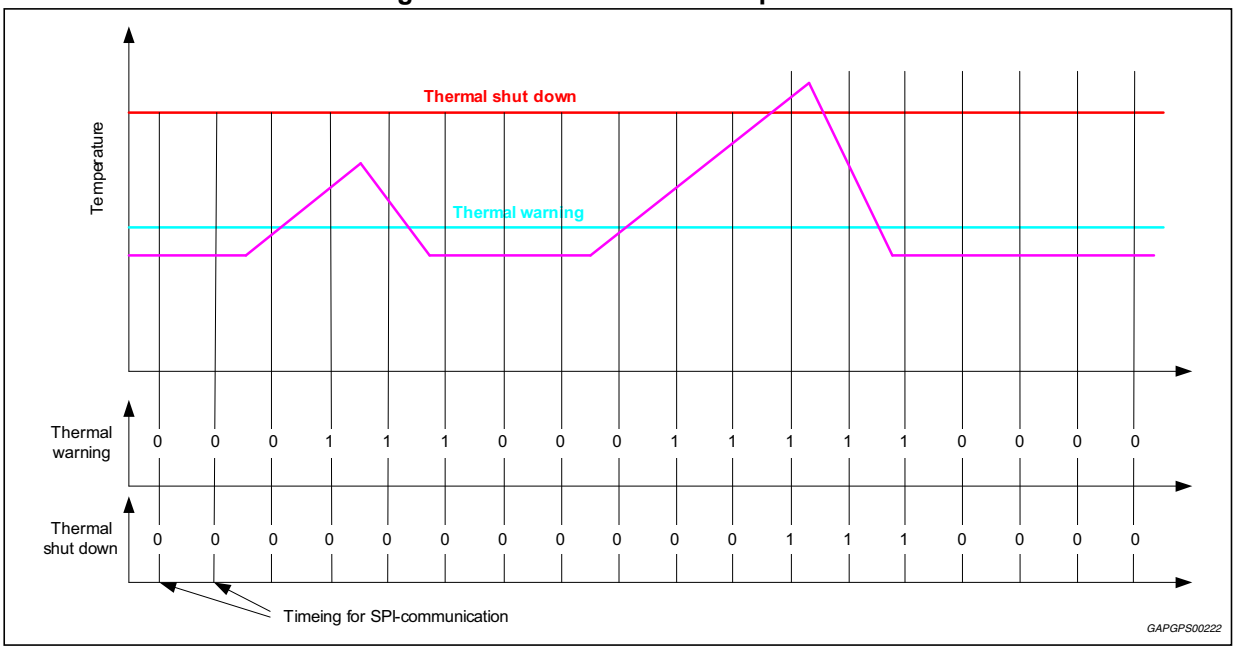
Thermal warning

If the measured value is higher than the thermal warning threshold, T_W (*Table 15*), for t_{TW} (*Table 18*)the appropriate thermal warning bit for that output is set in the SPI Status register (bit D8 of status registers 1 - 4, *Section 5.2.2*). No other action is taken. Reading the status registers clears the T_W bit(s) once the device is cooled sufficiently. This failure detection is used for all outputs.

Thermal shutdown

When the measured temperature exceeds the thermal shutdown threshold, T_{SD}, a failure is detected. This failure detection is filtered for t_{OT} (40 µs typ., *Table 18*). After t_{OT} the output is shut down immediately and all of the set point and control variables are set to zero. This disables the output from further actuation until the over temperature condition is removed and appropriate status register(s) (status registers 1 - 4, *Section 5.2.2*)) are read. Reading the status registers clears the T_{SD} bits once the device is cooled sufficiently. This failure detection is used for all outputs.

Figure 28. Thermal detection / protection behavior.



4.8.5 Power ground loss (PGND-loss)

PGND-loss continuously monitors the voltage between SGND and PGNDxy. If the measured value is higher than V_{PG_L} (*Table 16*) for longer than t_{PGND_L} (*Table 18*) a failure is detected. This sets the PGNDL_Qx bit (*Section 5.2.2*) and sets all of the set point and control variables to zero disabling the output. There is a power ground loss bit for each output even though Output 1 shares power ground with Output 2 and Output 3 shares power ground with Output 4. It is not possible to switch on the output as long as the failure is detected.

Once the power ground loss condition is removed the outputs are re-enabled by reading the appropriate status register (SPI Status register 1 - 4). This clears the failure bit in the status register and re-enables the output for use. This failure detection is used for all outputs.

The status of the failure is shown via SPI. PGND-loss is latched and can be reset only by accessing this register when the failure does not exist anymore.

4.8.6 Signal ground loss (SGND-loss)

The SGND-loss monitors the voltage between SGND and PGNDxy. If the measured value is higher than V_{SG_L} (*Table 16*) for t_{SGND_L} (*Table 18*) a failure is detected. After this time ALL outputs are switched off immediately and the driver is shut down. The SPI communication is possible but there is a threshold shift at the logic output drivers due to an additional substrate diode in the ground path between PGNDxy and SGND (see *Section 5.2.1*).

4.8.7 Freewheeling diode loss detection (Dx-loss)

Freewheeling diode loss is detected by measuring the current through the output clamping structure. If the clamping structure is used for more than t_{DX_L}(*Table 18*) a Dx_Loss is detected and the appropriate Status register bit (bit D5 of status registers 1 - 4, *Section 5.2.2*) is latched on. This bit can only be cleared once the failure is removed and the status register is read.

4.8.8 SPI-failure

There are 3 possible SPI-failures:

- parity failure (PARITY_F)
- clock failure (SPICLK_F)
- data failure (DATA_F)

In case of any SPI-Failure the next transmission to the master contains the following data:

MSB															LSB
received address				1	1	1	1	1	1	1	1	1	1	1	Parity
A3	A2	A1	A0	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Parity failure:

A parity failure is detected if the total number of '1's in the message is not odd. The PARITY_F bit of status register 0 is set and master message is ignored (no change of the data). The corresponding status message returned to the master after a parity failure contains the received address and only ‘1’s for the data bits. The PARITY_F bit can be cleared by accessing address 0.

SPI clock failure:

The L9375 counts the number of SPICLK positive edges during SPICS actuations (SPICS=’0’). If this number is unequal to 16 an error is detected and the message is not used (no change of the data) and the SPICLK_F bit in the status address 0 is set. The corresponding status message returned to the master after a Clock failure contains the received address and only ‘1’s for the data bits. The SPICLK_F bit can be cleared by accessing address 0.

Data failure:

A SPI command with data content that is not allowed produces a data failure (DATA_F).

The Data_F bit in the SPI status register 0 is set if the master writes invalid data to the config-registers (address 2, 14 and 15). When this failure occurs all data in these addresses are not modified (no change in the content at these registers).The Data_F bit can be cleared by accessing address 0.

4.8.9 CLKIN-failure

CLKIN-failure (CLKIN_F) is detected if the input frequency (*Table 17*) at the CLKIN pin is out of the specified range for t_{CLK_F}.(*Table 18*). Once this failure is detected all outputs are switched off immediately, all set points, control variables, and counters are reset to zero and the sync_counter is set to one. This frequency is monitored by an internal oscillator. This oscillator used to clock all internal nodes otherwise driven by CLKIN.

All failures which occur due to a CLKIN-failure are not reflected in any SPI-register. Only a sync failure will be reflected. Failures which occurred prior to a CLKIN failure are not deleted or overwritten.

The CLKIN_F bit can be cleared by accessing address 0 once the failure is removed.

4.8.10 Sync-failure

Sync failure detects a timing error in the output command synchronization. The master µC programs a timing window (STW, *Section 4.3*) where accessing to status address 0 is not allowed. If there is an access to Status address 0 when the STW flag is set then a sync-failure is generated (SYNC_F = 1). Also, a SYNC_F will be detected if there is no SPI traffic at all between two SYNC_SIG events. This status will be read out on the subsequent SPI transfer.

Without a SYNC_SIG or at sync-failure there is no effect for the actuation and setpoints

A sync-failure detection results in two consecutive error flags (SYNC_F = 1).

To re-synchronize the L9374LF a SYNC_TRIG signal must be sent.

4.8.11 Current not reachable failure (Q3 & Q4)

The Current Not Reachable failure is detected when the current controller control variable is set to $1FF_{(Hex)}$ or the current measurement sign_bit is set ('1') for more than t_{CURR_F} (8ms typ). Once a CNR is detected the CNRx bit for that output is set to '1' and the ISAT value is reset (see sections, *4.5.4*, *4.6.1* and, *5.2.1*).

The Current Not Reachable detection is used for outputs Q3 and Q4 only.

Table 36. Fault diagnostic summary

Failure	Output state	Effect	Reset behavior
Openload	off	– bit is set (latched)	Access SPI-register
Undercurrent	on	– bit is set (filtered) see *Section 4.8.1: Undercurrent / openload*	Access SPI-register
Overload	on	– bit is set (latched) – output is switched off – all set points / current / duty cycle / durations are kept at zero	Access SPI-register
Over temperature	on	– bit is set (latched) – output is switched off – all set points / current / duty cycle / durations are kept at zero	Access SPI-register
PGND-loss	on + off	– bit is set (latched) – output is switched off – all set points / current / duty cycle / durations are kept at zero	Access SPI-register
SGND-loss	on + off	– No constraints at all functions – SPI-communication has to be possible – The SPI-bit SGND_L is set after the filter time (tSGND_filt) – All channels are switched off after tSGND_filt and all current setpoints are deleted – The sync-parameters are not cleared; sync-counter is not reset	Access SPI-register
Dx-loss	on	– bit is set (latched)	Access SPI-register

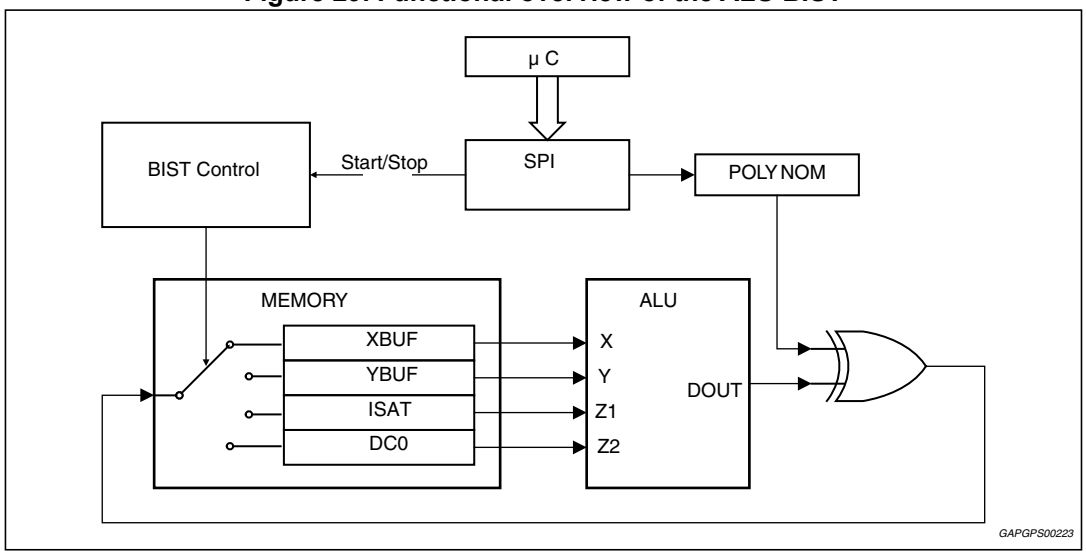
Table 36. Fault diagnostic summary (continued)

Failure	Output state	Effect	Reset behavior
SPI: Parity failure odd	on + off	– bit is set (latched) – data are not used	Access SPI-register
SPI: SPICLK-failure n <> 16	on + off	– bit is set (latched) – data are not used	Access SPI-register
SPI: Data-failure	on + off	– bit is set (latched) – data are not used (within a register)	Access SPI-register
CLKIN-failure	on + off	– bit is set (latched) – all outputs switched off immediately – all set points / current / duty cycle / durations are kept at zero – all counters are kept at zero – all synchronization values are kept at zero (reset, sync, STW) – there is no influence at all status register	Access SPI-register
Sync-failure STW_V_MIN < X < STW_V_MAX	on + off	– bit is set (latched)	Access SPI-register
Under voltage @ VS	on + off	– all outputs switched off immediately – all set points / current / duty cycle /durations are kept zero – all counters are kept at zero – all synchronization values are kept at zero (reset, sync, STW) – all status register are kept at zero – all input, outputs and data buffer are kept at default	-

4.8.12 ALU- BIST (Build in self test)

The ALU BIST is based on a Cyclic Redundancy Check (CRC) value calculation. For this reason it is possible to bring the sequencer, which controls the calculation of the current regulation ALU, into a special BIST mode. This mode is programmable via SPI using a special sequence of commands. The BIST is enabled when the fast switch off (FSOFF_ALL = ‘10’) command is given. The BIST then starts when the Res_CCV command (Res_CCV = ‘01’) along with a characteristic polynomial is programmed via SPI into register 15 (see *Section 5.1.9*). The BIST is autonomous, once it is started, it cannot be interrupted. The internal registers are used to provide values to the ALU during the BIST. These registers will be reset at the start of the BIST. After the BIST has finished the BIST busy bit (status address 5, bit D9) is reset and the CRC checksum is available. The checksum and can be read out via SPI from the ISAT_Q3 register (status address 8, bits D0 - D9, *Section 5.2.5*). The BIST mode can then be exited when the fast switch off all command is reversed (FSOFF_ALL = ‘01’). The used registers will be cleared to their power-on reset state when the L9374LF exits BIST mode.

Figure 29. Functional overview of the ALU BIST



To achieve test coverage higher than 97% with the BIST the following 4 polynomial values are recommended.

1. 194d (1100 0010)
2. 225d (1110 0001)
3. 212d (1101 0100)
4. 245d (1111 0101)

Sequence to perform the ALU built in self test during application:

1. Initiate the BIST sequencer; SPI command address: 2, FSOFF_ALL = 10).
   Note: The sequencer is then waiting for the programming of the characteristic polynomial to start the BIST.
2. Program the characteristic polynomial (SPI command address 15 RL= xxxxxxxx) while setting Res_CCV (=’01’). While the BIST is running BIST busy bit (BIST_BUSY Status address 5, bit D9) is set to ‘1’.
   Note: Programming address 15 starts the BIST sequence. At the beginning of the

sequence the internal registers are reset. It's not possible to interrupt the BIST. When the BIST is completed, the BIST busy bit is reset to'0' and the checksum is available to be read.
The BIST_BUSY bit reflects the actual status of the sequencer. 1: BIST is running or has been run previously and no current regulation is possible.

3. Readout the BIST checksum value located in status address 8, bits D0 - D9).
4. Repeat steps 2 and 3 until all of the polynomials have been run through the sequencer.
5. To exit the BIST mode write FSOFF_ALL = '01' (command address 2, bits D4 & D5). At this point you must re-program a new RL value (SPI command address 15, RL = xxxxxxxx).
   Note: Once leaving the BIST mode the internal registers are set to default values. After exiting the BIST mode and providing a new RL value the sequencer is ready to learn a new current regulation.

It is possible to program new current regulator set values in the same SPI access loop (Address. 0 to 15) where the BIST is stopped and a new RL value is written.

Affected internal registers from BIST:

XBuf Register for intermediate results

YBuf Register for intermediate results

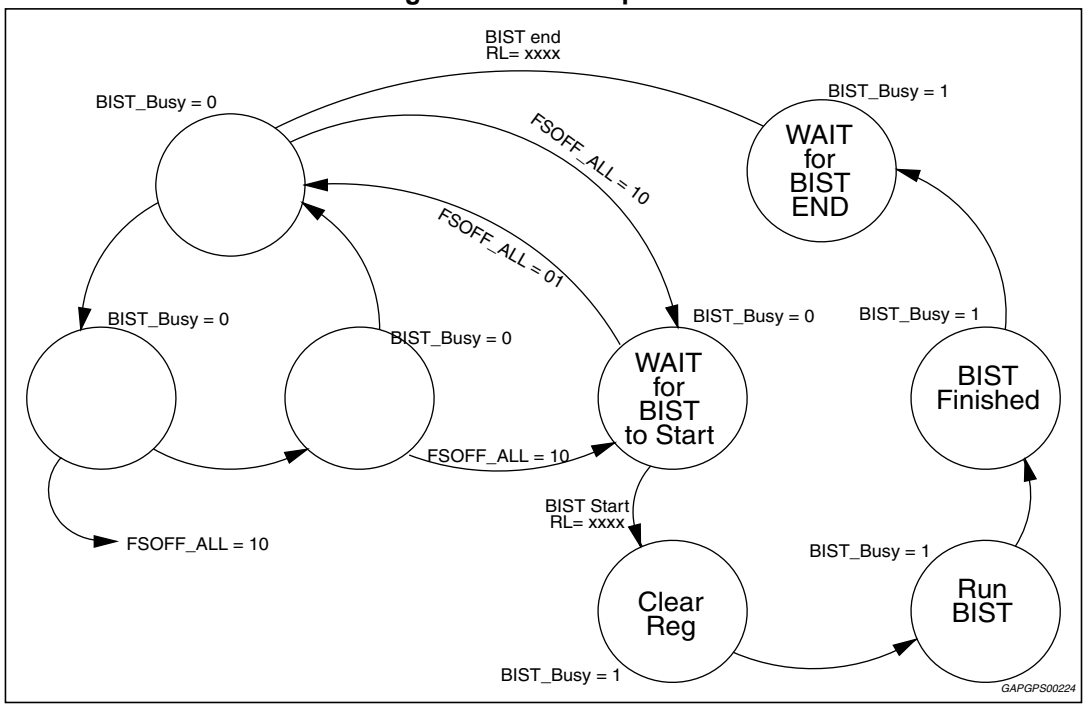
DC0 Register for intermediate result of DC

ISAT_Q3 Integration register for Channel 3

The contents of these register are reset at the initiation and completion of the BIST.

Just using the fast switch off command alone (FSOFF_ALL='10) does not initiate a BIST. This action will only initiate the sequencer into the BIST ready state. The BIST will not be started until programing a polynomial via SPI into address 15 is completed. Until that point the internal registers will not be reset. It is possible to leave the BIST ready state with by reversing the fast switch off command (Command address 2, FSOFF_ALL = '01'). The sequencer is then ready for new current regulation commands.

Figure 30. BIST sequence



4.8.13 Silent valve driver test (SVDT)

The silent valve driver test (SVDT) checks the DMOS Output and valve load integrity. Because the valve is switched on for a very short time during the test, the current in the loads remains very low. Subsequently the valves are not actuated and there is no observable valve noise.

The SVDT is initiated via a SPI command and automatically tests all outputs sequentially. It is not possible to restart the SVDT while it is in the middle of a test. However the SVDT can be interrupted by setting the SYNC_TRIG bit (Command register 2, bit D10).

The following status monitors are used during an SVDT:

Table 37. Status monitored during SVDT

Status	Bit description	Bit(s)
Off- State Open Load	OL_Qx	D0
Under Current	UC_Qx	D1
Over current	OC_Qx	D2
Over Temperature	OT_Qx	D3
Loss of freewheeling diode	Dx_Loss	D5

The SVDT SPI command is a 2 bit command where only one combination is acceptable to begin the test

Table 38. SVDT command

SVDT command (Address 2)	Bit 1	Bit 0
Not Possible	0	0
Normal Operation / No test	0	1
SVDT Active (in test mode)	1	0
Not Possible	1	1

When the SVDT has completed testing all of the outputs, the SVDT bits are reset ‘01’ and the test is halted. To restart the test the SVDT bits must be rewritten as ‘10’. All of the results are stored within the SPI output status registers (SPI addresses 1 - 4, section *5.2.2*). Accessing the output status registers after the SVDT is completed clears these registers. It is important to note that reading these addresses during an SVDT test also clears the status bits.

The SVDT sequence begins at the next SYNC_SIG after initiating the SVDT command. It is important to disable edge shaping (Command Address 2, bits D8 & D7 = ‘10’, section *5.1.3*) during the SVDT test for accurate results. This can be done in the same command.

The SVDT will run in a loop until completed even if the programmed sync register cycle time (RESET_VALUE) is shorter than the SVDT actuation time.

Figure 31. Timing between each output test

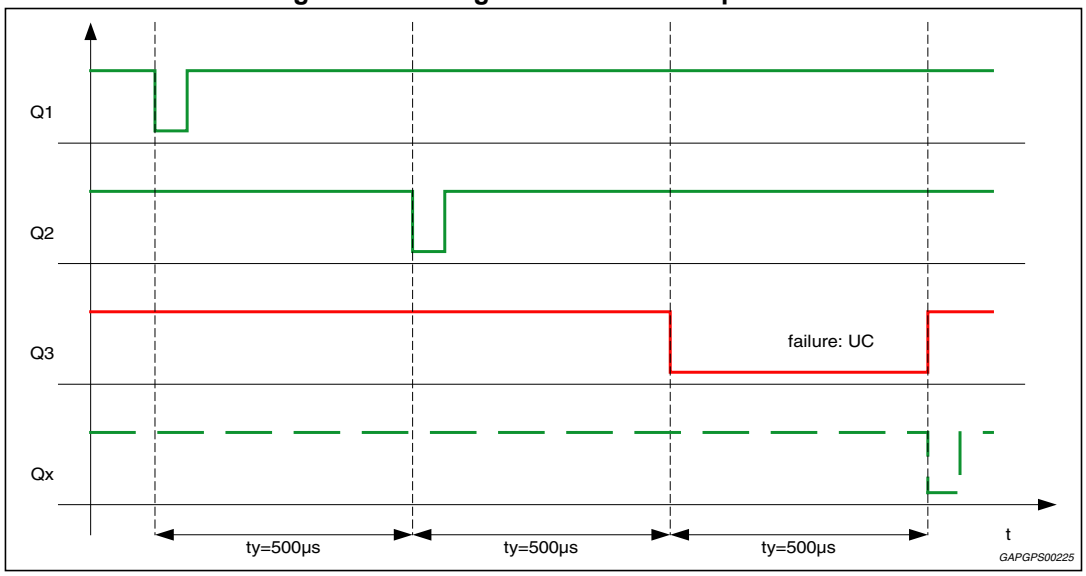
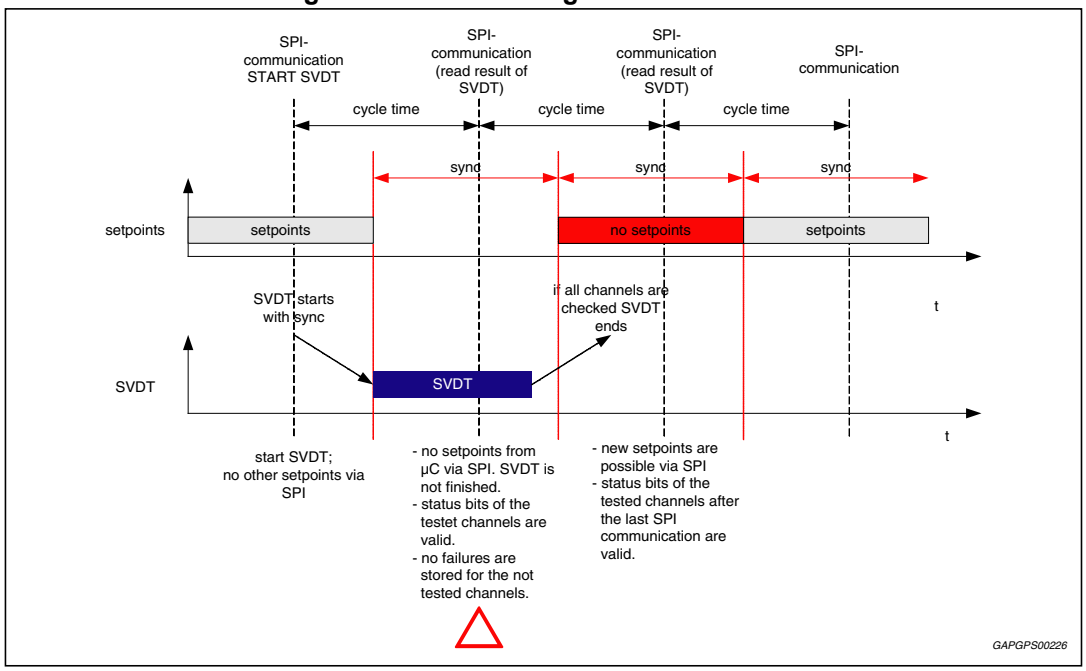


Figure 32. SVDT-Timing with SPI-transfer:



SVDT test sequence

1. Disable Edge Shaping (Command address 2, bits D8 & D7 = ‘10’)
2. Initiate SVDT (Command address 2; bits D1 & D0 = ‘10’)
3. Qx switches on at the next sync-signal (sequence of actuation: Q1..Q4)
4. Because the output is actuated the output current increases.
5. At time tx, if the output current has exceeded the under current value, I_{UC}, the output is switched off.
6. If the over current threshold (I_{OC}) is achieved prior to tx then the output is immediately disabled and an over current condition is detected.
7. The output will switch off any time prior to exceeding time, t_y, if the undercurrent threshold, I_{UC}, has been met.
8. After the output is disabled if the output clamps the voltage to V_Z (35V) a Dx_Loss is detected.
9. If an Over temperature is not detected then the SDVT test is passed
10. The SVDT will then test at Qx+1 until all 4 outputs have been tested.

Criterion for passing:

- no overcurrent
- Current value increases and reached undercurrent value within time ty (I_{Qx}>I_{UC}) & (tx<t<ty).
- Channels with a freewheeling diode does not have a clamping thus do not report a Dx_Loss condition

SPI:

- no failure at all Output status registers (Status Addresses 1 - 4).
- Qx_ON = 1

Figure 33. Passing test diagram

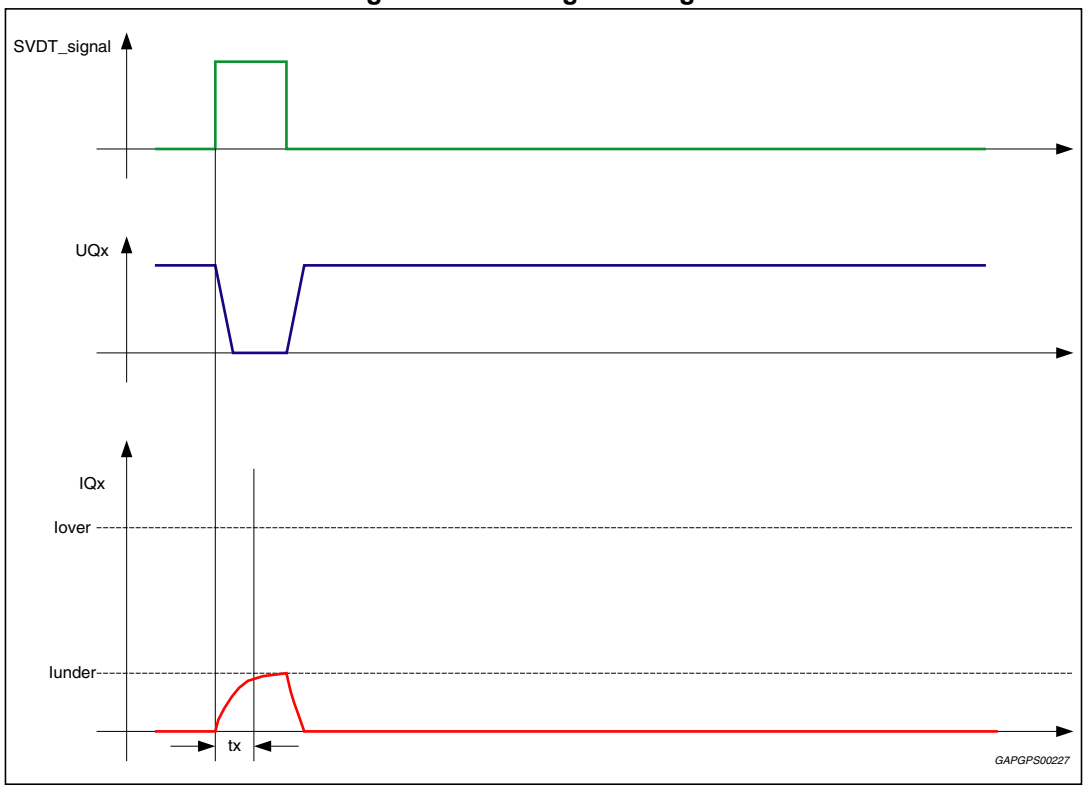
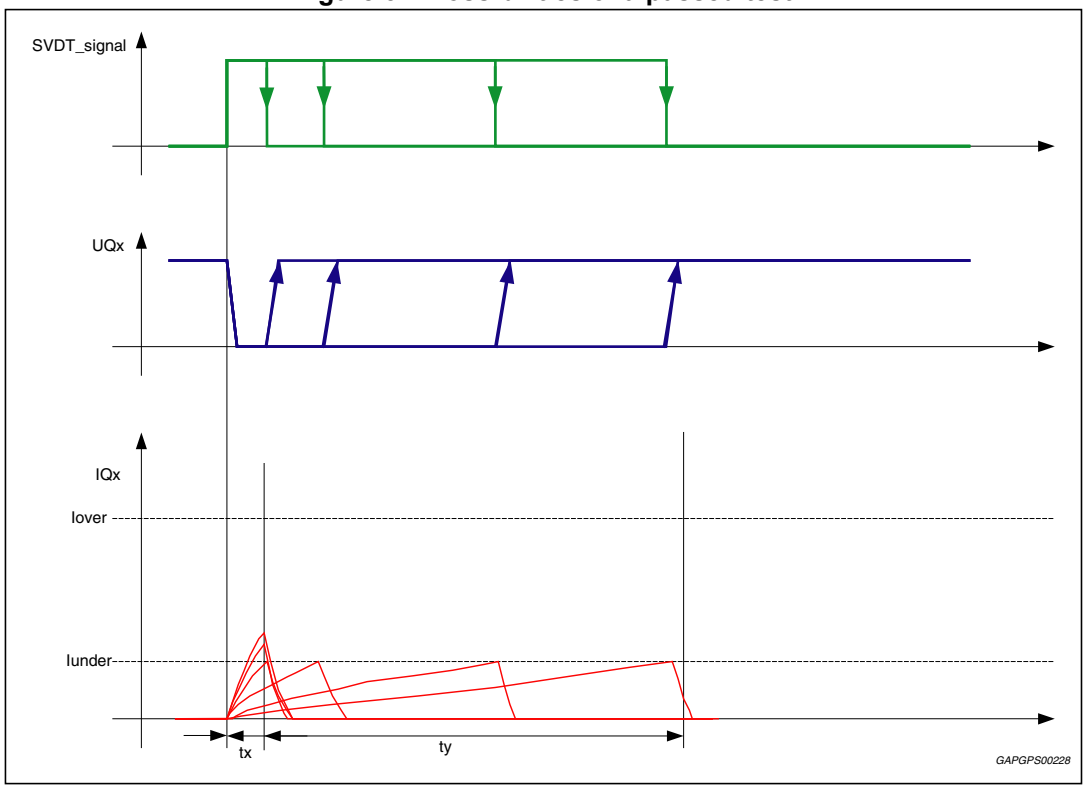
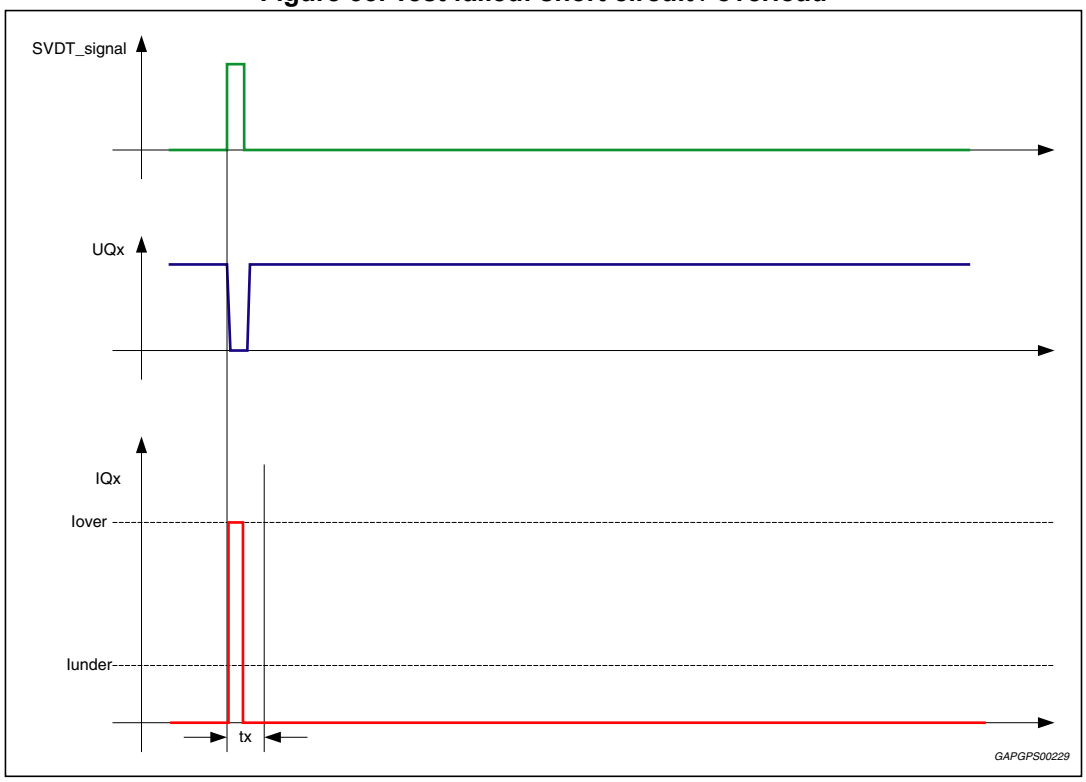


Figure 34. Possibilities of a passed test



The SVDT test examples

Figure 35. Test failed: short circuit / overload



A failed test sequence for overload condition:

1. Disable Edge Shaping (Command address 2, bits D8 & D7 = ‘10’)
2. Initiate SVDT (Command address 2; bits D1 & D0 = ‘10’)
3. Qx switches on at the next sync-signal (sequence of actuation: Q1..Q4)
4. The output current increases and reached I_{OL} before tx is reached
5. Output Qx is switched off for overload protection and the overload bit (bit D0 of the status registers D1 - D4).
6. After the output is disabled if the output clamps the voltage to V_Z (35V) a Dx_Loss is detected.
7. If an Over temperature is not detected then the SDVT test is passed
8. The SVDT will then test at Qx+1 until all 4 outputs have been tested.

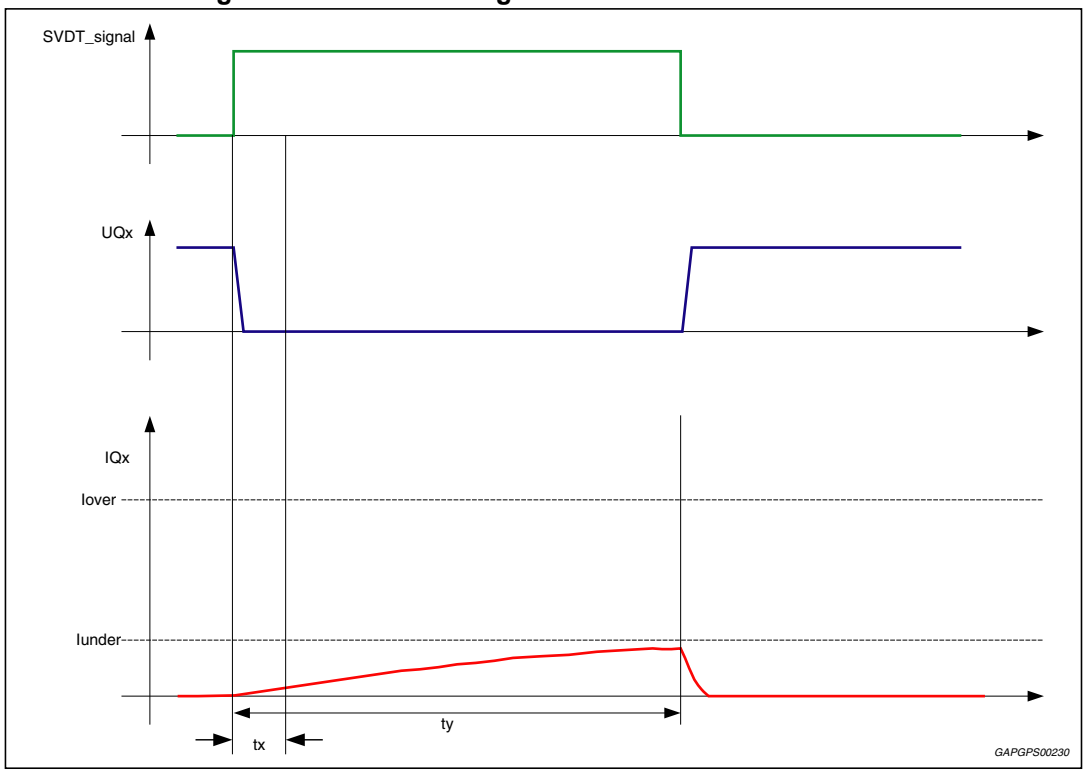
Criterion:

- The output current increases and reaches overcurrent value within the test time tx

SPI:

- Status registers 1 - 4, OL_Qx bit is set.

Figure 36. Test failed: high resistive load / undercurrent



A failed test sequence for under current condition

The test sequence:

1. Disable Edge Shaping (Command address 2, bits D8 & D7 = ‘10’)
2. Initiate SVDT (Command address 2; bits D1 & D0 = ‘10’)
3. Qx switches on at the next sync-signal (sequence of actuation: Q1..Q4)
4. The output current increases but does not reach the undercurrent value, I_{UC}.
5. After ty the output is switched off.
6. After the output is disabled if the output clamps the voltage to V_Z (35V) a Dx_Loss is detected.
7. If an Over temperature is not detected then the SDVT test is passed
8. The SVDT will then test at Qx+1 until all 4 outputs have been tested.

Criterion:

- the current value does not reach the undercurrent value within time ty

SPI:

- Status registers 1 - 4, UC_Qx bit is set.

Table 39. SVDT status

Dx_loss	Overcurrent OC_Qx	Under Current UC_Qx	Description
0	0	0	Test is passed
0	0	1	High resistive load or high inductive load
0	1	0	Overcurrent: short circuit to supply voltage or short circuit of the load
0	1	1	Not possible
1	0	0	Dx-loss
1	0	1	Dx-loss+ high resistive load or high inductive load
1	1	0	Dx-loss + short circuit to supply voltage or short circuit of the load
1	1	1	Not possible

5 Programmers guide

This programmers guide is a reference section intended to aid in the L9374LF interface software development. The L9374LF uses SPI messaging for all of its communication into or out of the device. The Command registers are written to and the Status registers are read.

5.1 Command registers

The Command Registers are registers written to by the MASTER µC to actuate the L9374LFs various functions. Each command consists of an address, data, and a parity bit (refer to *Chapter 4.1: SPI serial peripheral interface* for more details).

5.1.1 Sync + Sync-trigger register (address 0)

MSB															LSB
0	0	0	0	SYNC_ TRIG	RESET_VALUE				SYNC_VALUE						Parity
A3	A2	A1	A0	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 40. Sync + Sync-trigger register

Sync + sync-trigger	Name	Bit Location	Number of bits	bit time
Synchronization value	SYNC_VALUE	D0-D5	6	250 µs
Reset value (highest 4 Bits)	RESET_VALUE	D6-D9	4	1 ms
Sync-trigger	SYNC_TRIG	D10	1	-

For this section see *Chapter 4.3: Synchronization controller* for more details

Synchronization value:

This 6-bit-value represents a time value. At this time the new set points are processed.
Resolution of LSB: 250 µs

Reset value:

With this value the time base of the synchronization can be modified.
Resolution of LSB: 1 ms

The MSB of the RESET_VALUE (D9) affects the bit times for the Sync Trigger Window, the Duration x, and the Duration y parameters.

Sync-trigger:

The synchronization is re-triggered by setting this bit to ‘1’. After a re-synchronization the internal logic will clear this bit automatically.

If the SVDT is active and still running, it will be interrupted by setting the SYNC_TRIG bit (See also *Chapter 4.3* section on *Synchronization controller programming*).

5.1.2 Sync tolerance window (STW) register (address 1)

MSB														LSB
0	0	0	1	0	STW_V_MAX					STW_V_MIN				Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

STW value:

These two sets of 5 bits each define a window (between min and max) where accessing address ‘0’ within this window will cause a sync failure indication (SYNC_F).

To keep the resolution meaningful for the entire range of Sync Triggering the resolution is dependant on the RESET_VALUE MSB. For programming the two values to the STW the master has to write both values (2 x 5 bit).

Table 41. STW value

STW value	Name	Bit location	Number of bits	bit time RESET_VALUE ≤ $0111_{(2)}$	bit time RESET_VALUE ≥ $1000_{(2)}$
STW value min.	STW_V_MIN	D0 - D4	5	250 µs	500 µs
STW value max.	STW_V_MAX	D5 - D9	5	250 µs	500 µs

For this section see *Chapter 4.3: Synchronization controller* for more details

5.1.3 Configuration register 1 (address 2)

MSB														LSB
0	0	1	0	x	x	EDGE_SH		FSON_EN	FSOFF_ALL		CLKIN_S		SVDT		Parity
A3	A2	A1	A0	free	free	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 42. Configuration register 1

Config register	Name	Bit location	Number of bits
Silent valve driver test	SVDT	D0 - D1	2 Bit
CLKIN frequency 1MHz / 250kHz	CLKIN_S	D2 - D3	2 Bit
Fast switch off all	FSOFF_ALL	D4 - D5	2 Bit
Fast switch on enable (general)	FSON_EN	D6	1 Bit
Edge shaping on / off	EDGE_SH	D7 - D8	2 Bit

Silent valve driver test (SVDT):

These two bits (D0 & D1) are normally set to ‘01’. Writing '10' to these two bits starts the silent valve driver test.

(for more details see *Chapter 4.8.13: Silent valve driver test (SVDT)*)

Table 43. Silent valve driver test (SVDT)

Bit 1	Bit 0	Combination
0	0	Not valid
0	1	Normal condition / no test
1	0	Active
1	1	Not valid

Writing not valid bit combinations generates a SPI-data-failure and causes that specific SPI command to be ignored and subsequent returning Status Register data to be set to all ‘1’s.

CLKIN input frequency 1MHz / 250kHz (CLKIN_S):

These two bits set the ratio between internal and external clock (See*Chapter 4.2: Clock*).

Table 44. CLKIN_S

Bit 1	Bit 0	Combination
0	0	Not valid
0	1	250 kHz
1	0	1 MHz
1	1	Not valid

Writing not valid bit combinations generates a SPI-data-failure and causes that specific SPI command to be ignored and subsequent returning Status Register data to be set to all ‘1’s.

Fast switch off (FSOFF_ALL):

These two bits (D4 & D5) are normally set to ‘01’. With these two bits set to ‘10’ all outputs are switched off immediately (without regard to the synchronization). When set to active these bits clear the fast switch on enable (FSON_EN) bit at address 3 and all set points. It is not possible to activate any output with status FSOFF_ALL = ‘10’ (active). This bit pattern is also used to initiate the ALU built in self test, or BIST, (for more details on the Built In Self Test see *Chapter 4.8.12: ALU- BIST (Build in self test)*).

Table 45. Fast switch off

Bit 1	Bit 0	Combination
0	0	Not Valid
0	1	Normal condition
1	0	Active → all outputs are off
1	1	Not Valid

Writing Not Valid bit combinations generates a SPI-data-failure and causes that specific SPI command to be ignored and subsequent returning Status Register data to be set to all ‘1’s.

Fast switch on enable (FSON_EN):

This bit (D6) is normally set to ‘0’. Setting this bit (‘1’) enables the SPI ability to drive outputs directly. With this bit set, writing to address 3 (bits D0 -D3) turns or off outputs Q1 - Q4. All of the bits in Command Register 3 are reset when FSON_EN is reset (‘0’).

Edge shaping (EDGE_SH)

Edge Shaping option allows the user to incorporate a slower more EMI sensitive slope to the output waveform. By setting these bits the user is able to turn on / off edge shaping for all outputs (see *Section 3.3.4: Output timing characteristics*). There is no option to select individual outputs for edge shaping. When performing the SVDT it is recommended that Edge Shaping be turned OFF.

Table 46. Edge shaping

Bit 1	Bit 0	Combination
0	0	Not Valid
0	1	Edge Shaping **ON** for all outputs
1	0	Edge Shaping **OFF** for all outputs
1	1	Not Valid

Writing Not Valid bit combinations generates a SPI-data-failure and causes that specific SPI command to be ignored and subsequent returning Status Register data to be set to all ‘1’s.

5.1.4 Fast switch-on (FSON) register (address 3)

MSB															LSB
0	0	1	1	x	x	x	x	x	x	x	ON_4	ON_3	ON_2	ON_1	Parity
A3	A2	A1	A0	free	free	free	free	free	free	free	D3	D2	D1	D0	P

Table 47. Fast switch-on

Configuration register	Bit Location	Name
Switch on Q1	D0	ON_1
Switch on Q2	D1	ON_2
Switch on Q3	D2	ON_3
Switch on Q4	D3	ON_4

If the fast switch on enable bit (FSON_EN) is set, writing 1 to the bit ON_X switches the output on 100%. A ‘0’ written to the fast switch on enable pin will disable this function. Any outputs on as a result of an ONx bit being high will be turned off.

The fast switch off all bits (FSOFF_ALL) turn off all channels immediately (it does not depend on the synchronization) and clear all bits at this address. The fast switch off all (FSOFF_ALL) command has the highest priority.

5.1.5 Duration registers (address 4 and 5)

MSB															LSB
0	1	0	0	x	D_Q2					D_Q1					Parity
0	1	0	1	x	D_Q4					D_Q3					Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

The output can be driven in two stages by one SPI transfer, a duty cycle for a duration and then a second duty cycle. These registers provide the initial duration information. Two duration values are available in each register.

Table 48. Register duration value

Register address	Duration parameter	Number of bits	Bit location	Output
4	D_Q1	5 Bit	D4 - D0	Q1
4	D_Q2	5 Bit	D9 - D5	Q2
5	D_Q3	5 Bit	D4 - D0	Q3
5	D_Q4	5 Bit	D9 - D5	Q4

The duration bit resolution depends on the synchronization timer RESET_VALUE MSB:

Table 49. Duration bit resolution

RESET_VALUE MSB (add.0, bit D9)	Resolution of duration
0	250 µs
1	500 µs

5.1.6 Duty cycle register (address 6 to 9)

MSB															LSB
0	1	1	0	x	x	DUTY1_Q1									Parity
0	1	1	1	x	x	DUTY2_Q1									Parity
1	0	0	0	x	x	DUTY1_Q2									Parity
1	0	0	1	x	x	DUTY2_Q2									Parity
A3	A2	A1	A0	free	free	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

The value of these registers represent the outputs Q1 and Q2 set point duty cycles. Address 6 and 8 provide the initial duty cycle used during the duration specified in the duration register (address 4). Addresses 7 and 9 provide the duty cycles used after the duration specified in address 4 has expired.

Table 50. Duty cycle register (address 6 to 9)

Register address	Duty cycle register	Number of bits	Bit location	Name
6	Output 1 Duty cycle 1	9	D0 - D8	DUTY1_Q1
7	Output 1 Duty cycle 2	9	D0 - D8	DUTY2_Q1
8	Output 2 Duty cycle 1	9	D0 - D8	DUTY1_Q2
9	Output 2 Duty cycle 2	9	D0 - D8	DUTY2_Q2

The resolution is 0.2% per LSB.

$000_{(H)}$ = 0% Duty Cycle

$1F4_{(H)}$ = 100% Duty cycle.

To achieve the full diagnostic capability do not use a duty cycle of less than 5%(or $19_{(H)}$).

5.1.7 Current / duty cycle registers (address 10 to 13)

MSB															LSB
1	0	1	0	x	x	CURRENT/DUTY1_Q3									Parity
1	0	1	1	x	x	CURRENT/DUTY2_Q3									Parity
1	1	0	0	x	x	CURRENT/DUTY1_Q4									Parity
1	1	0	1	x	x	CURRENT/DUTY2_Q4									Parity
A3	A2	A1	A0	free	free	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

These registers provide a numerical value that is either translated as a current regulation set point or a duty cycle set point. This depends on the Current Control / PWM (CCPWM_Qx) bits found in Register 14. Either or both outputs can be set as either a current controlled output or a fixed PWM output independently (for details see *Chapter 3.3.6: Q3 / Q4 (current controller)*).

Table 51. Current / duty cycle registers

Register address	Duty cycle register	Number of bits	Bit location	Name
10	Output 1 Current / Duty cycle 1	9	D0 - D8	CURRENT/DUTY1_Q1
11	Output 1 Current / Duty cycle 2	9	D0 - D8	CURRENT/DUTY2_Q1
12	Output 2 Current / Duty cycle 1	9	D0 - D8	CURRENT/DUTY1_Q2
13	Output 2 Current / Duty cycle 2	9	D0 - D8	CURRENT/DUTY2_Q2

Resolution of LSB: 3.522mA

$000_{(H)}$ = 0 Amps

$1FF_{(H)}$ = 1.8 Amps

5.1.8 Configuration register 2 - current control / over-voltage threshold (address 14)

MSB															LSB
1	1	1	0	x	x	x	OV_TH_Q2		OV_TH_Q1		CCPWM_Q4		CCPWM_Q3		Parity
A3	A2	A1	A0	free	free	free	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 52. Configuration register 2 - current control / over-voltage threshold

Configuration register	Number of bits	Bit location	Name
Current Controller / PWM Switch Q3	2 bit	D1 - D0	CCPWM_Q3
Current Controller / PWM Switch Q4	2 bit	D3 - D2	CCPWM_Q4
Overload threshold Q1	2 bit	D5 - D4	OV_TH_Q1
Overload threshold Q2	2 bit	D7 - D6	OV_TH_Q2

Current controller / PWM enable

These two bits control the PWM or current regulation algorithm for outputs Q3 and Q4. When disabled the output reverts to a PWM only configuration as in outputs Q1 and Q2.

Table 53. Current controller off Q3 / Q4

Bit 1	Bit 0	Combination
0	0	Not Valid
0	1	Current controller enabled (PWM Control Off)
1	0	PWM Control Only (Current Control Off)
1	1	Not Valid

Writing Not Valid bit combinations generates a SPI-data-failure and causes that specific SPI command word to be ignored and subsequent returning Status Register data to be set to all ‘1’s.

Overload threshold Qx:

These two bits change the threshold of the overload diagnosis of channel Q1 and Q2. (See *Table 15.* for values and *4.8.3: Overload* for a functional description)

Table 54. Overload threshold Q1 / Q2

Bit 1	Bit 0	Combination
0	0	Not Valid
0	1	Overload threshold 1
1	0	Overload threshold 2
1	1	Not Valid

Writing Not Valid bit combinations generates a SPI-data-failure and causes that specific SPI command word to be ignored and subsequent returning Status Register data to be set to all ‘1’s.

5.1.9 Configuration register 3 (CCV reset and load resistance values) (address 15)

MSB														LSB
1	1	1	1	x	Res_CCV		RL_SPI							Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 55. Configuration register 3

Configuration register	Number of bits	Bit location	Name
Reset current controller values	2 bit	D9 - D8	Res_CCV
RL_SPI	8 bit	D7 - D0	RL_SPI

Reset current controller values command (Res_CCV):

The Current Controller values are reset and the new RL_SPI is used after the reset time. During the reset phase the current controller regulation variable I_{SAT} is set to zero and no current regulation is possible. When changing the RL_SPI it is necessary to reset the current controller by giving this command

Table 56. Reset current controller values command

Bit 1	Bit 0	Combination
0	0	Not Valid
0	1	Reset
1	0	Normal Condition
1	1	Not Valid

Writing Not Valid bit combinations generates a SPI-data-failure and causes that specific SPI command word to be ignored and subsequent returning Status Register data to be set to all ‘1’s.

RL_SPI:

RL_SPI is an 8 bit value representing the expected load resistance driven by the current controller outputs (Q3 and Q4). This value is used for both current controllers. The controller performance is best with RL_SPI close to the real value of the load resistor.

Table 57. Load resistor value

D7	D6	D5	D4	D3	D2	D1	D0	SPI - Bit
8 Ω	4 Ω	2 Ω	1 Ω	1/2 Ω	1/4 Ω	1/8 Ω	1/16 Ω	RL_SPI

5.2 Status registers

5.2.1 General status (address 0)

MSB															LSB
0	0	0	0	0	SGND_L	FSON_S	CLKIN_State		EN	CLKIN_F	SYNC_F	DATA_F	SPICLK-F	PARITY_F	Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 58. Status registers

General status	Number of bits	Bit location	Name
Parity-failure	1 Bit	D0	PARITY_F
SPI-Clock-failure	1 Bit	D1	SPICLK_F
Data-failure	1 Bit	D2	DATA_F
Sync-Failure	1 Bit	D3	SYNC_F
CLKIN-failure	1 Bit	D4	CLKIN_F
EN Status	1 Bit	D5	EN
1MHz / 250kHz Status	2 Bits	D7 - D6	CLKIN_S
Fast Switch On Enable Status	1 Bit	D8	FSON_S
SGND loss	1 Bit	D9	SGND_L

Parity-failure:

If a parity-failure occurs during any command write this bit is set. It is cleared by accessing address 0.

SPI-Clock-failure:

This bit is set by a clock-failure (number of positive edges of SPICLK within SPICS = low is unequal 16) and is cleared by accessing address 0.

Data-failure:

This bit is set if the master writes invalid data to the configuration-register (Data: SVDT, CLKIN_S and FSOFF_ALL / CCPWM_Qx / OV_THx, EDGE_SH_OFF). Reset of this bit is done by accessing address 0. If the master tries to write invalid data to one of the input registers its content will not be changed (invalid write access is ignored, SPI data failure is set).

Sync-failure:

This bit is set by a Sync-failure and is cleared when the failure does not exist anymore. (shows the actual status)

(see *Synchronization failure*)

CLKIN-failure:

If the frequency of CLKIN-signal is not in a specified range a CLKIN-failure occurs (CLKIN_F = 1). The specification range can be changed via SPI (CLKIN_STATE). This bit (CLKIN_F) can be cleared by accessing this address.

Hardware EN status:

The EN Status bit reflects the level of the Enable (EN) pin. If the value of the Enable pin was low since the last access to this register the status EN is low (low sensitive signal). This bit is cleared by accessing this address.

1 MHz / 250 kHz status:

These bits reflect the two CLKIN_S bits from the Command register 2 (bits D3 and D2). This is done to verify that the L9374LF has received the CLKIN_S command.

Table 59. CLKIN_S command

Bit 1	Bit 0	Combination
0	0	Not possible
0	1	250 kHz
1	0	1 MHz
1	1	Not possible

Fast switch on enable (FSON_EN) status

This bit shows the actual status of Fast switch on enable (FSON_EN) bit found in Command register 2, bit D6.

SGND loss:

After sensing a signal ground loss for t_{SGND_filt} the SPI-bit SGND_L is set, all channels are switched off, and all current set points are reset. The sync-parameters and the sync_counter are not cleared. With SGND-loss a SPI-communication is still possible by using PGND as a ground reference. When the loss of SGND no longer exists the SGND_L bit is reset after an access to address 0 (refer to section *4.8.6: Signal ground loss (SGND-loss)*).

5.2.2 Output status Q1... Q4 (address 1 to 4)

Outputs Q1 and Q2 (addresses 1 and 2):

MSB															LSB
0	0	0	1	0	OV_TH1	TW_1	Q1_OFF	Q1_ON	DL_1	PGNDL_12	TSD_1	OVER_1	UC_1	OL_1	Parity
0	0	1	0	0	OV_TH2	TW_2	Q2_OFF	Q2_ON	DL_1	PGNDL_12	TSD_1	OVER_2	UC_2	OL_2	Parity
A3	A2	A1	A0	free	D9	free	D7	D6	D5	D4	D3	D2	D1	D0	P

Outputs Q3 and Q4 (addresses 3 and 4):

MSB															LSB
0	0	1	1	0	CCPWM_3	TW_3	Q3_OFF	Q3_ON	DL_3	PGNDL_34	TSD_3	OVER_3	UC_3	OL_3	Parity
0	1	0	0	0	CCPWM_4	TW_4	Q4_OFF	Q4_ON	DL_4	PGNDL_34	TSD_4	OVER_4	UC_4	OL_X4	Parity
A3	A2	A1	A0	free	D9	free	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 60. Output status Q1... Q4

Channel status	Number of bits	Name
Openload	1 Bit	OL_x
Undercurrent	1 Bit	UC_x
Overload	1 Bit	OVER_x
Thermal Shutdown	1 Bit	TSD_x
PGND-lost	1 Bit	PGNDL_xy
Dx-lost	1 Bit	DL_x
Output ON	1 Bit	Qx_ON
Output OFF	1 Bit	Qx_OFF
Current / PWM controller Select	1 Bit	CCPWM_x
overload threshold	1 Bit	OV_THx
Thermal warning	1 Bit	TW_x

(see section *4.8: Diagnostics* for details for mot of the parameters in this section)

Open load:

The open load bit is set if the voltage at output Qx in off-state is lower than the failure-threshold V_{OL} (*Table 15.*). This bit is cleared by accessing this address (Refer to section *4.8.1* for more details).

Undercurrent:

The undercurrent bit shows the status of the undercurrent detection (I_{UC},*Table 15.*). This bit is cleared by accessing this address (Refer to section *4.8.1* for more details).

Overload:

When the current through output Qx in on-state is higher than the failure-threshold (I_{OL}, *Table 15.*) the overload bit is set and all set point and control variables for the offending output are set to zero. This bit can be cleared by accessing this address (Refer to section *4.8.3* for more details).

Thermal shutdown:

thermal shutdown is detected if the temperature of the DMOS is above T_{SD}, (*Table 15.*) for t_{OVL} (*Table 18.*) (refer to section*4.8.4* for more details).

PGND-loss:

This bit is set by a power ground loss and is cleared by accessing this address (Refer to section *4.8.5* for more details)

Loss of freewheeling diode (Dx-loss):

This bit is set by loss of the freewheeling diode and is cleared by accessing this address (refer to section *4.8.7* for more details).

Gate voltage on status (Qx_ON):

This bit shows the status of the output driver gate. A comparator monitors the voltage of the gate.

If there is any actuation of the output between two SPI transfers the cycle time this bit is set. The bit is cleared by accessing this address (Refer to section*: Gate monitoring* for more information).

Gate voltage off status (Qx_OFF):

This bit shows the status of the output driver gate. A comparator monitors the voltage of the gate.

If the output is disabled between two SPI transfers the cycle time this bit is set. The bit is cleared by accessing this address (Refer to section*: Gate monitoring* for more information).

Current / PWM controller select:

This bit is set when the Current Controlled is disabled and the PWM Control is active (refer to*: Current controller / PWM enable* for details).

Table 61. Current / PWM controller select

CCPWM	Status current controller off
0	Current Controller Enabled
1	PWM Control Enabled (Current Control disabled)

Overload threshold:

This bit shows the overload threshold selected in Configuration register 2 (Command address E) actual status of the threshold of the overload diagnosis (refer to *Table 15.*)

Table 62. Overload threshold

OV_TH	Status overload threshold	Typical overload threshold value
0	Overload threshold 1	7.5 A
1	Overload threshold 2	8.5 A

5.2.3 VD (address 5)

MSB															LSB
0	1	0	1	0	BIST_BUSY	VD									Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 63. VD / BIST BUSY general status

General status	Number of bits	Name
VD	9	VD
BIST BUSY	1	BIST_BUSY

VD:

The value supply voltage at the D13 pin is measured and stored in Status Address 5 (refer to section *3.3.12: VD measurement* for more details)

Table 64. VD value

SPI - Bit	D8	D7	D6	D5	D4	D3	D2	D1	D0
VD-value	16 V	8 V	4 V	2 V	1 V	1/2 V	1/4 V	1/8 V	1/16 V

BIST BUSY:

This bit shows the status of the BIST state machine (details see *Chapter 4.8.12*)

Table 65. BIST BUSY status

BIST_BUSY flag	BIST status
0	BIST not running
1	BIST is running

5.2.4 Output duty (address 6 and 7)

MSB															LSB
0	1	1	0	0	CNR3	Out_duty_Q3									Parity
0	1	1	1	0	CNR4	Out_duty_Q4									Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 66. Output duty

Output status	Number of bits	Name
Output duty	9 Bit	Out_duty_Qx
Current Not Reachable	1 Bit	CNRx

Output duty:

This value shows the duty cycle commanded by the current controller (9 bit control variable) just prior to the time of the SPI transfer. The resolution of LSB is that f the PWM command register of 0.2%.

Timing example:

- Time base: 5 ms between SPI transfers
- Output-frequency: 4 kHz → 250 µs

The Out_Duty_Qx value shows the duty cycle at 4,75 ms.

The maximum value read is $1FF_{(H)}$. This occurs when the output current cannot reach the commanded value (refer to section *3.3.6: Q3 / Q4 (current controller)* for more information).

Current Not Reachable (CNRx):

This bit is set if the control variable of the current at output Qx shows the maximum value ($1FF_{(H)}$) for more than 8 ms (typ.). This bit can be cleared by accessing this address, when the failure does not exist anymore (refer to section *3.3.6: Q3 / Q4 (current controller)* for more information).

5.2.5 ISAT-Qx (address 8 + 9)

MSB															LSB
1	0	0	0	0	ISAT_Q3										Parity
1	0	0	0	1	ISAT_Q4										Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 67. ISAT_Qx

Channel status	Number of bits	Name
ISAT_Qx	10 Bit	ISAT_Qx

ISAT_Qx:

ISAT_Qx is an internal value of the current controller. This is used by the current controller to provide accurate current regulation (refer to section *3.3.6: Q3 / Q4 (current controller)* for more details).

5.2.6 Reference diode voltage measurement (V_FWD) (address 10)

MSB															LSB
1	0	1	0	0	0	V_FWD									Parity
A3	A2	A1	A0	free	free	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 68. Reference diode voltage measurement

Description	Number of bits	Resolution per bit
Reference diode forward voltage drop	9 Bit	7.8 mV typ

Reference diode forward voltage (V_FWD):

The V_FWD value is a measurement of an internal reference diode using a fixed reference current. This corresponds to the forward voltage of one of the current controller output freewheeling diodes.
The resolution of the LSB is 7.8mV (typ.) and the parameter range is:

Table 69. V_FWD value

SPI - Bit	D8	D7	D6	D5	D4	D3	D2	D1	D0
V_FWD	2 V	1 V	1/2 V	1/4 V	1/8 V	1/16 V	1/32 V	1/64 V	1/128 V

Note: Refer to section : V_FWD for more information.

5.2.7 Sense resistor measurement (Rs) (address 11)

MSB															LSB
1	0	1	1	0	0	Rs									Parity
A3	A2	A1	A0	free	free	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 70. Sense resistor measurement

Channel status	Number of bits	Name
Sense resistor measurement	9 Bit	Rs

Refer to *Section 4.5.2* for more information)

The resolution of the LSB is 8.7mΩ (typ.) and the parameter range is:

Table 71. Rs value

SPI - Bit	D8	D7	D6	D5	D4	D3	D2	D1	D0
Rs-value	4 Ω	2 Ω	1 Ω	1/2 Ω	1/4 Ω	1/8 Ω	1/16 Ω	1/32 Ω	1/64 Ω

5.2.8 Current controller status register (CC-STATUS) (address 12)

MSB															LSB
1	1	0	0	0	Res_CCV		RL_SPI								Parity
A3	A2	A1	A0	free	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 72. Current controller status register

CC-register	Number of bits	name
Reset current controller values	2 Bit	Res_CCV
RL_SPI	8 Bit	RL_SPI

Res_CCV Feedback:

Res_CCV show the actual current controller reset state. This is not a copy of the bit received in the command register 15 (see *5.1.9*). The bit combination ‘01’ (reset) can only read via SPI if the communication runs during a current regulator reset.

RL_SPI feedback

RL_SPI is a copy of the received SPI-values (see *5.1.9: Configuration register 3 (CCV reset and load resistance values) (address 15)*).

5.2.9 Error average (address 13 + 14)

MSB															LSB
1	1	0	1	0	0	ERRORAVG_Q3									Parity
1	1	1	0	0	0	ERRORAVG_Q4									Parity
A3	A2	A1	A0	free	free	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

Table 73. Error average

Error average	Number of bits	Name
Error average	9 Bit	ERRORAVG_Qx

(refer to *Section 4.5.2 : Load current measurements* for detailed information)

5.2.10 Reserved (address 15)

This register is not used. Answer will always be 0xF001.

MSB															LSB
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	Parity
A3	A2	A1	A0	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	P

6 Register block functional overview

6.1 Input command register block overview (MOSI data)

Note: without address-bits and parity

Table 74. Overview input register block

address	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
0 SYNC_REG	**sync_ trig**	**RESET_VALUE**				**SYNC_VALUE**					
		sync_ res_3	sync_ res_2	sync_ res_1	sync_ res_0	sync_ value_5	sync_ value_4	sync_ value_3	sync_ value_2	sync_ value_1	sync_ value_0
Power on reset status	0	0	0	0	0	0	0	0	0	0	0
1 STW_V	**free**	**STW_V_MAX**					**STW_V_MIN**				
		STW_ max_4	STW_ max_3	STW_ max_2	STW_ max_1	STW_ max_0	STW_ min_4	STW_ min_3	STW_ min_2	STW_ min_1	STW_ min_0
Power on reset status	0	0	0	0	0	0	0	0	0	0	0
2 CONFIG 1	**free**	**free**	**EDGE_SH**		**FSON_ EN**	**FSOFF_ALL**		**CLKIN_S**		**SVDT**	
			EDGE_SH _OFF_1	EDGE_SH _OFF_0		F_{SOFF_1}	F_{SOFF_0}	CLKIN_S_ 1	CLKIN_S_ 0	SVDT_1	SVDT_0
power on reset status	0	0	0	1	0	0	1	0	1	0	1
3 FSON	**free**	**free**	**free**	**free**	**free**	**free**	**free**	**Q4_ON**	**Q3_ON**	**Q2_ON**	**Q1_ON**
Power on reset status	0	0	0	0	0	0	0	0	0	0	0
4 Duration Q1/Q2	**free**	**D_Q2**					**D_Q1**				
		D_{Q2_4}	D_{Q2_3}	D_{Q2_2}	D_{Q2_1}	D_{Q2_0}	D_{Q1_4}	D_{Q1_3}	D_{Q1_2}	D_{Q1_1}	D_{Q1_0}
power on reset status	0	0	0	0	0	0	0	0	0	0	0
5 Duration Q3/Q4	**free**	**D_Q4**					**D_Q3**				
		D_{Q4_4}	D_{Q4_3}	D_{Q4_2}	D_{Q4_1}	D_{Q4_0}	D_{Q3_4}	D_{Q3_3}	D_{Q3_2}	D_{Q3_1}	D_{Q3_0}
power on reset status	0	0	0	0	0	0	0	0	0	0	0
6 DUTY1_Q1	**free**	**free**	**DUTY1_Q1**								
			$DU1_{Q1\_8}$	$DU1_{Q1\_7}$	$DU1_{Q1\_6}$	$DU1_{Q1\_5}$	$DU1_{Q1\_4}$	$DU1_{Q1\_3}$	$DU1_{Q1\_2}$	$DU1_{Q1\_1}$	$DU1_{Q1\_0}$
Power on reset status	0	0	0	0	0	0	0	0	0	0	0
7 DUTY2_Q1	**free**	**free**	**DUTY2_Q1**								
			$DU2_{Q1\_8}$	$DU2_{Q1\_7}$	$DU2_{Q1\_6}$	$DU2_{Q1\_5}$	$DU2_{Q1\_4}$	$DU2_{Q1\_3}$	$DU2_{Q1\_2}$	$DU2_{Q1\_1}$	$DU2_{Q1\_0}$

Table 74. Overview input register block (continued)

address	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
power on reset status	0	0	0	0	0	0	0	0	0	0	0
8 DUTY1_Q2	**free**	**free**	**DUTY1_Q2**								
			$DU1_{Q2\_8}$	$DU1_{Q2\_7}$	$DU1_{Q2\_6}$	$DU1_{Q2\_5}$	$DU1_{Q2\_4}$	$DU1_{Q2\_3}$	$DU1_{Q2\_2}$	$DU1_{Q2\_1}$	$DU1_{Q2\_0}$
power on reset status	0	0	0	0	0	0	0	0	0	0	0
9 DUTY2_Q2	**free**	**free**	**DUTY2_Q2**								
			$DU2_{Q2\_8}$	$DU2_{Q2\_7}$	$DU2_{Q2\_6}$	$DU2_{Q2\_5}$	$DU2_{Q2\_4}$	$DU2_{Q2\_3}$	$DU2_{Q2\_2}$	$DU2_{Q2\_1}$	$DU2_{Q2\_0}$
power on reset status	0	0	0	0	0	0	0	0	0	0	0
10 CUR/DTY1_Q3	**free**	**free**	**CURRENT/DUTY1_Q3**								
			$CU1_{Q3\_8}$	$CU1_{Q3\_7}$	$CU1_{Q3\_6}$	$CU1_{Q3\_5}$	$CU1_{Q3\_4}$	$CU1_{Q3\_3}$	$CU1_{Q3\_2}$	$CU1_{Q3\_1}$	$CU1_{Q3\_0}$
power on reset status	0	0	0	0	0	0	0	0	0	0	0
11 CUR/DTY2_Q3	**free**	**free**	**CURRENT/DUTY2_Q3**								
			$CU2_{Q3\_8}$	$CU2_{Q3\_7}$	$CU2_{Q3\_6}$	$CU2_{Q3\_5}$	$CU2_{Q3\_4}$	$CU2_{Q3\_3}$	$CU2_{Q3\_2}$	$CU2_{Q3\_1}$	$CU2_{Q3\_0}$
power on reset status	0	0	0	0	0	0	0	0	0	0	0
12 CUR/DTY1_Q4	**free**	**free**	**CURRENT/DUTY1_Q4**								
			$CU1_{Q4\_8}$	$CU1_{Q4\_7}$	$CU1_{Q4\_6}$	$CU1_{Q4\_5}$	$CU1_{Q4\_4}$	$CU1_{Q4\_3}$	$CU1_{Q4\_2}$	$CU1_{Q4\_1}$	$CU1_{Q4\_0}$
power on reset status	0	0	0	0	0	0	0	0	0	0	0
13 CUR/DTY2_Q4	**free**	**free**	**CURRENT/DUTY2_Q4**								
			$CU2_{Q4\_8}$	$CU2_{Q4\_7}$	$CU2_{Q4\_6}$	$CU2_{Q4\_5}$	$CU2_{Q4\_4}$	$CU2_{Q4\_3}$	$CU2_{Q4\_2}$	$CU2_{Q4\_1}$	$CU2_{Q4\_0}$
power on reset status	0	0	0	0	0	0	0	0	0	0	0
14 CONFIG_2	**free**	**free**	**free**	**OV_TH_Q2**		**OV_TH_Q1**		**CCPWM_Q4**		**CCPWM_Q3**	
				OV_TH_Q2_1	OV_TH_Q2_0	OV_TH_Q1_1	OV_TH_Q1_0	CCPWM_Q4_1	CCPWM_Q4_0	CCPWM_Q3_1	CCPWM_Q3_0
power on reset status	0	0	0	0	1	0	1	0	1	0	1
15 CONFIG_3	**free**	**Res_CCV**		**RL_SPI**							
		Res_CCV_1	Res_CCV_0	RL_7	RL_6	RL_5	RL_4	RL_3	RL_2	RL_1	RL_0
power on reset status	0	x	x	x	x	x	x	x	x	x	x

6.2 Status register block overview (MISO data)

Note: without address-bits and parity

Table 75. Overview answer register block

address	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
0 G_INFO	**free**	**SGND_L**	**STATE_FAST**	**CLKIN_State** CLKIN_S_1	CLKIN_S_0	**HW_EN**	**CLKIN_F**	**SYNC_F**	**Data_F**	**SPICLK_F**	**PARITY_F**
power on reset status	0	0	0	0	1	0	0	1	0	0	0
1 STATUS_Q1	**free**	**OV_TH**	**TW_1**	**Q1_OFF**	**Q1_ON**	**DL_Q1**	**PGNDL_Q1**	**TEMP_Q1**	**OVER_Q1**	**UC_Q1**	**OL_Q1**
power on reset status	0	0	0	0	0	0	0	0	0	0	0
2 STATUS_Q2	**free**	**OV_TH**	**TW_2**	**Q2_OFF**	**Q2_ON**	**DL_Q2**	**PGNDL_Q2**	**TEMP_Q2**	**OVER_Q2**	**UC_Q2**	**OL_Q2**
power on reset status	0	0	0	0	0	0	0	0	0	0	0
3 STATUS_Q3	**free**	**CCPWM_Q4**	**TW_3**	**Q3_OFF**	**Q3_ON**	**DL_Q3**	**PGNDL_Q3**	**TEMP_Q3**	**OVER_Q3**	**UC_Q3**	**OL_Q3**
power on reset status	0	0	0	0	0	0	0	0	0	0	0
4 STATUS_Q4	**free**	**CCPWM_Q4**	**TW_4**	**Q4_OFF**	**Q4_ON**	**DL_Q4**	**PGNDL_Q4**	**TEMP_Q4**	**OVER_Q4**	**UC_Q4**	**OL_Q4**
power on reset status	0	0	0	0	0	0	0	0	0	0	0
5 VD	**free**	**BIST_BUSY**	**VD_8**	**VD_7**	**VD_6**	**VD_5**	**VD_4**	**VD_3**	**VD_2**	**VD_1**	**VD_0**
power on reset status	0	0	0	0	0	0	0	0	0	0	0
6 OUT_DUTY_Q3	**free**	**CNR_Q3**	**OUT_DUTY_Q3** OUTDQ3_8	OUTDQ3_7	OUTDQ3_6	OUTDQ3_5	OUTDQ3_4	OUTDQ3_3	OUTDQ3_2	OUTDQ3_1	OUTDQ3_0
power on reset status	0	0	0	0	0	0	0	0	0	0	0
7 OUT_DUTY_Q4	**free**	**CNR_Q4**	**OUT_DUTY_Q4** OUTDQ4_8	OUTDQ4_7	OUTDQ4_6	OUTDQ4_5	OUTDQ4_4	OUTDQ4_3	OUTDQ4_2	OUTDQ4_1	OUTDQ4_0
power on reset status	0	0	0	0	0	0	0	0	0	0	0

Table 75. Overview answer register block (continued)

address	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
8 ISAT_Q3	**free**	**ISAT_Q3**									
		ISAT_Q3_9	ISAT_Q3_8	ISAT_Q3_7	ISAT_Q3_6	ISAT_Q3_5	ISAT_Q3_4	ISAT_Q3_3	ISAT_Q3_2	ISAT_Q3_1	ISAT_Q3_0
power on reset status	0	0	0	0	0	0	0	0	0	0	0
9 ISAT_Q4	**free**	**ISAT_Q4**									
		ISAT_Q4_9	ISAT_Q4_8	ISAT_Q4_7	ISAT_Q4_6	ISAT_Q4_5	ISAT_Q4_4	ISAT_Q4_3	ISAT_Q4_2	ISAT_Q4_1	ISAT_Q4_0
power on reset status	0	0	0	0	0	0	0	0	0	0	0
10 V_FWD	**free**	**free**	**V_FWD**								
			V_FWD_8	V_FWD_7	V_FWD_6	V_FWD_5	V_FWD_4	V_FWD_3	V_FWD_2	V_FWD_1	V_FWD_0
power on reset status	0	0		x	x	x	x	x	x	x	x
11 RS	**free**	**free**	**Rs**								
			RS_8	RS_7	RS_6	RS_5	RS_4	RS_3	RS_2	RS_1	RS_0
power on reset status	0	0									
12 CC-STATUS	**free**	**Res_CCV**	**RL_SPI**	**RL_SPI**							
		Res_CCV_1	Res_CCV_0	RL_7	RL_6	RL_5	RL_4	RL_3	RL_2	RL_1	RL_0
power on reset status	0	0	1	0	1	0	0	0	0	0	0
13 ERRORAVG_Q3	**free**	**free**	**ERRORAVG_Q3**								
			ERRORAVG_Q3_8	ERRORAVG_Q3_7	ERRORAVG_Q3_6	ERRORAVG_Q3_5	ERRORAVG_Q3_4	ERRORAVG_Q3_3	ERRORAVG_Q3_2	ERRORAVG_Q3_1	ERRORAVG_Q3_0
power on reset status	0	0	0	0	0	0	0	0	0	0	0
14 ERRORAVG_Q4	**free**	**free**	**ERRORAVG_Q4**								
			ERRORAVG_Q4_8	ERRORAVG_Q4_7	ERRORAVG_Q4_6	ERRORAVG_Q4_5	ERRORAVG_Q4_4	ERRORAVG_Q4_3	ERRORAVG_Q4_2	ERRORAVG_Q4_1	ERRORAVG_Q4_0
power on reset status	0	0	0	0	0	0	0	0	0	0	0
15 RESERVED	**RESERVED**										
answer to access	0	0	0	0	0	0	0	0	0	0	0

7 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK® packages, depending on their level of environmental compliance. ECOPACK® specifications, grade definitions and product status are available at: *www.st.com*.

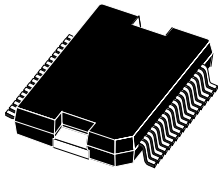
ECOPACK® is an ST trademark.

Figure 37. PowerSO-36 (slug down) mechanical data and package dimensions

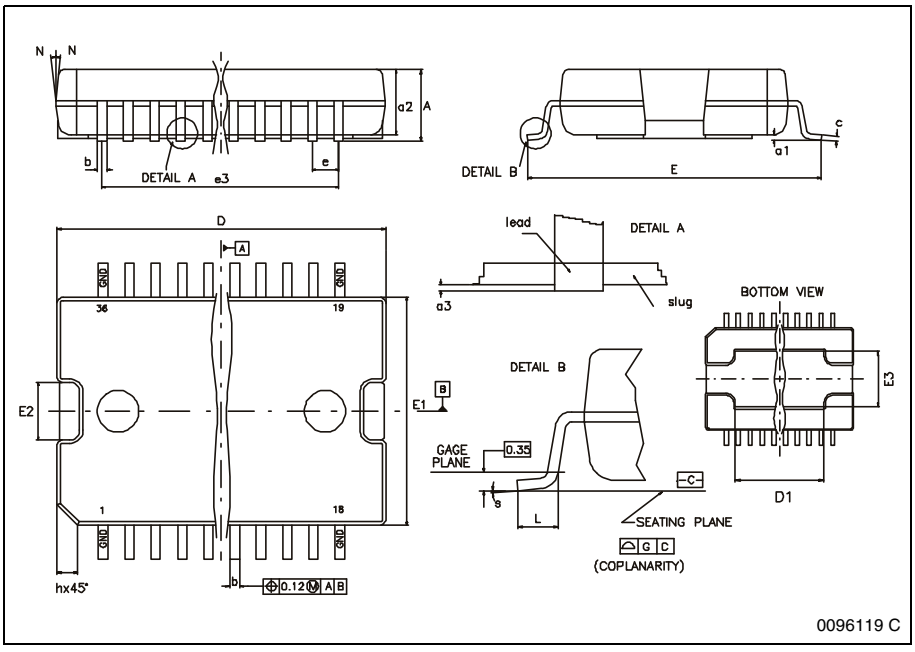
DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			3.60			0.1417
a1	0.10		0.30	0.0039		0.0118
a2			3.30			0.1299
a3	0		0.10			0.0039
b	0.22		0.38	0.0087		0.0150
c	0.23		0.32	0.0091		0.0126
D	15.80		16.00	0.6220		0.6299
D1	9.40		9.80	0.3701		0.3858
E	13.90		14.5	0.5472		0.5709
E1	10.90		11.10	0.4291		0.4370
E2			2.90			0.1142
E3	5.80		6.20	0.2283		0.2441
e		0.65			0.0256	
e3		11.05			0.4350	
G	0		0.10			0.0039
H	15.50		15.90	0.6102		0.6260
h			1.10			0.0433
L	0.8		1.10	0.0315		0.0433
N	10° (max)					
s	8° (max)					

Note: “D and E1” do not include mold flash or protusions.
- Mold flash or protusions shall not exceed 0.15mm (0.006”)
- Critical dimensions are "a3", "E" and "G".

OUTLINE AND MECHANICAL DATA



PowerSO-36



8 Revision history

Table 76. Document revision history

Date	Revision	Changes
30-Oct-2013	1	Initial release.

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.

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