L6364

Datasheet

Dual channel transceiver IC for SIO and IO-Link sensor applications

QFN 20L (4x4 mm)

Product status link
L6364

Product summary	
Order code	**Package**
L6364Q	QFN 20L

SUSTAINABLE TECHNOLOGY

Features

- Supply voltage from 5 V to 35 V
- 5 V and 3.3 V compatible I/Os
- 5 V and 3.3 V, 50 mA linear regulators
- 50 mA DC-DC regulator with configurable frequency (0.5 MHz to 2 MHz) & voltage (5 V-10.5 V)
- Low dissipative (5 Ω) CQ and DIO output stages configurable in high side, low side, push/pull
- Configurable (0.11 A to 0.25 A) current limitation threshold of CQ and DIO lines
- Configurable (0.22 A to 0.5 A) current limitation threshold of CQ//DIO line (Join Mode)
- Fully protected:
  - Embedded reverse polarisation diode (DOUT pin)
  - Full zero current reverse polarity between Vplus, CQ, DIO and PGND pins
  - Configurable (up to 216°C) thermal shutdown threshold
  - 7-bit, calibrated, temperature measurement
  - Configurable (6.0 V to 15 V) Vplus undervoltage detection
  - CQ and DIO short-circuit current limit and reporting
- -40 to +150°C operating temperature
- Suitable to drive L, C and R loads
- Quartz-free IO-Link clock extraction and timing generation at COM2 (38.4k Baud) and COM3 (230.4k Baud)
- Integrated UART peripheral with M-sequence handling (inc. checksum) for all IO-Link sequences according to specification v1.1
- Single octet UART mode for unlimited M-sequence size and continuous data transfer
- Internal data buffer for up to 15 octets
- Transparent UART mode for special applications
- CQ and DIO switching time = 100 ns (2k Ω//2.2 nF load)
- 8 V Zener limits for fast demagnetization of inductive loads
- Two LED drivers with configurable (up to 8 mA) current
- Design to meet application requirements:
  - ESD IEC 61000-4-2 protection to 4 kV
  - EMC surge protection 2A/50 µs, (coupling 500 Ω)
- Smart format QFN-20L 4x4 mm package

Application

- Industrial sensors
- Factory automation
- Process control

Description

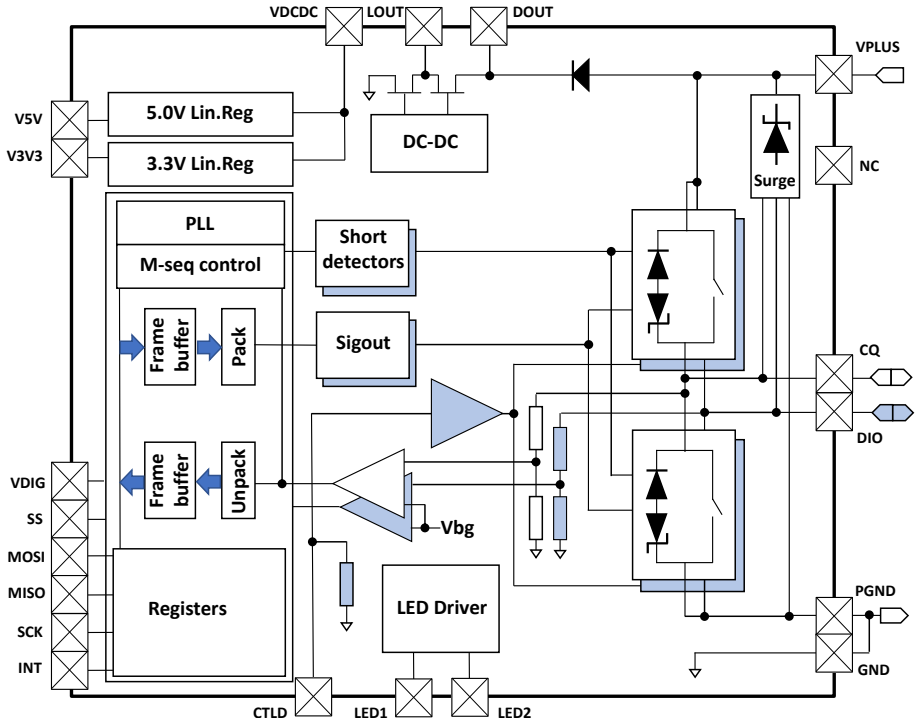
The L6364 is a dual channel transceiver for industrial sensor applications.

It has been designed to support the IO-Link standard and acts as a bridge between a microcontroller with a sensor or actuator function and a 24 V supply and signaling cable.

In normal operation the L6364 is configured by the microcontroller via the SPI interface at startup. Typically, the L6364 then operates as a Single Input Output IOLink device driving the output lines as configured by the microcontroller. If the device is connected to an IO-Link master, then the master can initiate communication and exchange data with the microcontroller while the L6364 acts as a physical layer for the communication.

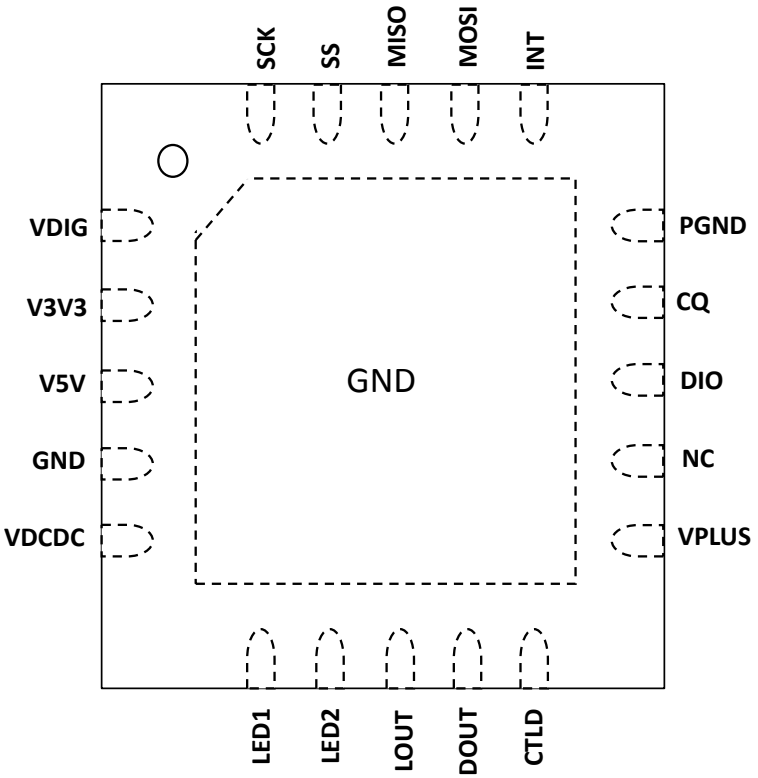
1 Block Diagram

Figure 1. **Block Diagram**



2 Package and pin-out

Figure 2. **Package and pinout - QFN**



PINOUT TOP THROUGH VIEW

N.B. GND exposed pad and GND pin to be shorted on PCB

Table 1. Pin Description

Group/Exposure	Pin number (QFN)	Name	Function	Type (1)
Line/External	11	V_{PLUS}	Line supply voltage	PWR
	14	CQ	Line data signal SIO/SDCI	ANA IO
	13	DIO	Line data signal DI/DO	ANA IO
	15	P_{GND}	Switch ground return	PWR
	4, TAB	GND	Ground	PWR
SPI/Internal/Dig	17	MOSI	SPI data, microcontroller to L6364	CI
	19	SS	SPI synchronization, slave select	CI
	20	SCK	SPI interface clock signal	CI
	18	MISO	SPI data, L6364 to microcontroller	COZ
	16	INT	Interrupt	CO
	1	V_{DIG}	SPI interface supply	PWR
	10	CTLD	Direct control of DIO output channel	CI
LED/External	6	LED1	LED1 source current	ANA O
	7	LED2	LED2 source current	ANA O
Low voltage supply/ Internal	3	V5V	Sensor and microcontroller supply	PWR
	2	V3V3		PWR
DCDC/Internal	9	D_{OUT}	VPLUS following diode protections	ANA IO
	8	L_{OUT}	Inductor power feed	ANA IO
	5	V_{DCDC}	DCDC supply output, intermediate supply	PWR
Unused/Internal	12	N/C	Not connected	-

1. *PWR: power, CI: CMOS input, CO: CMOS output, COZ: output with tristate function, ANA IO: Analogue input output, ANA O: Analogue output.*

3 Technical Data

3.1 Absolute Maximum Ratings

Absolute maximum ratings are those values beyond which damage to the device may occur. Functional operation under these conditions is not implied. All voltages are referenced to GND unless otherwise specified.

Table 2. Absolute maximum ratings

Symbol	Parameter	Value	Unit
V_{PLUS}	Supply Voltage (steady-state)	- 40 to + 40	V
	Supply Voltage (transient)	Internally limited	
V_{CQ}	HS or LS Output channel voltage (steady-state)	- 40 to + 40	V
	HS or LS Output channel voltage (transient)	Internally limited	
V_{DIO}	DIO channel voltage (steady-state)	- 40 to + 40	V
	DIO channel voltage (transient)	Internally limited	
V5V	5V voltage pin	- 1 to 7	V
V3V3	3.3V voltage pin	- 1 to 5	V
V_{DIG}, V_{LED1}, V_{LED2}	Digital pins end LED pins	- 1 to 7	V
V_{ESD}	Electrostatic protection (HBM)	2	kV
P_D	Power Dissipation	Internally limited	W
T_{LEAD}	Soldering temp. (20-40sec, cf. JEDEC J-STD-020C)	260	°C
T_{STOR}	Storage Temperature Range	-40 to 150	°C

Operation above the absolute maximum ratings may lead to instantaneous device failure. Operation of the L6364 between the operating ratings and the absolute maximum ratings leads to a reduced operating lifetime.

3.2 Thermal Characteristics

Table 3. Thermal data

Symbol	Parameter	Value		Unit
		QFN20L	CSP19	
$R_{th(JA)}$	Thermal resistance junction-ambient (FR4, Cu Thick. 35 µm, 2 layers, total exposed area = 5 mm^2; exposed pad soldered to Cu area with vias)	54	80	°C/W

3.3 Recommended operating conditioning

Table 4. Recommended operating conditions

Symbol	Parameter	Min.	Typ.	Max.	Unit
I_{QUIES}	Operating current supply, no pin currents, DCDC enables		3.0	3.5	mA
I_{QUIES_START}	Operating current supply on pin V_{PLUS} during startup			10	mA

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{SUP}	V_{PLUS} supply voltage, I_{V3V3}=50mA, (DCDC disabled)	4.5	24	35	V
V_{SUP}	V_{PLUS} supply voltage, I_{V5V0}=50mA, (DCDC disabled)	6	24	35	V
V_{SUP}	Minimum VPLUS (DCDC enabled) (see Figure 12)		10.5		V
$V_{DCDC\_5V\_MIN}$	Minimum VDCDC output voltage (V_{SET}) for use of V5V	6.1			V
$V_{DCDC\_3V3\_MIN}$	Minimum V_{3V3} for VDCDC		2.8		V
C_{BLK}	Blocking capacitor on VPLUS	100			nF
C_{EMC}	EMC blocking capacitor		470		pF
C_{V3V3}	Capacitor C_{V3V3}	1		10	µF
C_{V5V}	Capacitor C_{V5V} (V5V in use)	1		10	µF
C_{DOUT}	Capacitor C_{DOUT}	10			nF
C_{DCDC}	Capacitor C_{DCDC}		2.2		uF
L_{DCDC}	Inductor L_{DCDC}		220		uH
C_{QLOAD_MAX}	Maximum load capacitor CQ (see Figure 20)(1)			250	nF
$C_{DIOLOAD\_MAX}$	Maximum load capacitor DIO (see Figure 20) (1)			250	nF
$C_{JOINLOAD\_MAX}$	Maximum load capacitor JOIN mode (see Figure 21) (1)			500	nF
L_{CQLOAD_MAX}	Maximum load inductance CQ (see Figure 20)			(2)	mH
$L_{DIOLOAD\_MAX}$	Maximum load inductance DIO (see Figure 20)			(2)	mH
$L_{JOINLOAD\_MAX}$	Maximum load inductance JOIN mode (see Figure 21)			(2)	mH

1. *values measured with pure capacitive load.*
2. *unlimited, see Section 18 for further details.*

3.4 Electrical Characteristics

Electrical parameters are valid over the operating temperature and voltage range, unless otherwise stated.

Table 5. Receiver CQ/DIO

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_{THH}	Input threshold “H”	RF bit = 0 in CFG register (see Figure 17 and Figure 18 Register map).	10.5		13	V
V_{THL}	Input threshold “L”		8		11.5	V
V_{THHR}	Input threshold “H”	RF bit = 1 in CFG register (see Figure 17 and Figure 18 Register map).	-10%	(V_{PLUS}/1.8)-0.5	+10%	V
V_{THLR}	Input threshold “L”		-10%	(V_{PLUS}/1.8)+0.5	+10%	V
V_{HYS}	Hysteresis		0.5	1	1.5	V
V_{IN}	Input range CQ/DIO				35, V_{PLUS} +10	V
f_{BIT}	Data rate	BD=0		38.4		kBaud
f_{BIT}	Data rate	BD=1		230.4		kBaud
T_{BIT}	Bit time			$1/f_{BIT}$		µs
f_{CK}	Internal clock base		-10%	10	+10%	MHz

Table 6. Short-circuit and Wake-up detection

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{SHORT}	Set current tolerance	See Table 28	-20%	I_{SET}	+20%	mA
t_{SHORT}	Filter delay		-10%	14	+10%	µs
N_{RETRY}	Retries	SIO=1		2		
t_{RETRY}	Retry delay	SIO=1	-10%	50	+10%	µs
$t_{RESTART}$	Short-circuit restart time	SIO=1	-10%	100	+10%	ms

Table 7. POR (Power On Reset)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_{POR}	POR release threshold		1.6	2	2.5	V
V_{HYST}	POR hysteresis			0.1		V

Table 8. Output switches individual channels CQ/DIO

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
R_{SW}	Output resistance	I_{OUT}=100mA		5	10	Ω
V_{ZEN}	Zener voltage	I_{OUT}=10mA	6		10	V
		I_{OUT}=100mA		8		V
I_{SAT}	Saturated current			1.2		A

Table 9. Line surge protection, parameters with respect to any pair PGND, CQ, DIO, VPLUS

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
$V_{SURGE(CLAMP)}$	Voltage clamps protection threshold	abosorbed current < 40 uA	35	40	45	V

Table 10. Thermal shutdown

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
εT	Temperature accuracy	150°C	-10		10	°C
εT	Temperature accuracy	30°C	-5		5	°C
Θ_{HYST}	Thermal hysteresis			10		°C

Table 11. Digital pins

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
V_{DIG}	Voltage drop on digital pins	I = -4 mA			0.5	V
V_{DL}	Input low signal				0.15 V_{DIG}	V
V_{DH}	Input high signal		0.5 V_{DIG}			V

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
t_{cl}	Clock low phase	SCK	50			ns
t_{ch}	Clock high phase	SCK	50			ns
t_{ms}	Setup wrt. SCK	MOSI	10			ns
t_{mh}	Hold wrt. SCK	MOSI	10			ns
t_{ss}	Setup wrt. SCK	SS	10			ns
t_{sh}	Hold wrt. SCK	SS	10			ns
t_{md}	Output availability	MISO		18	40	ns
R_{PU}	Pull-up resistance	SS, SCK, MOSI	50		200	kΩ
R_{PD}	Pull-down resistance	CTLD	50		200	kΩ

Table 12. LED Driver

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
I_{LED}	Sink current base unit(1)	See Figure 10	-10%	0.5	+10%	mA

1. *The current supplied by each LED pin can be configured between 0 to 8 mA by LED1[3:0] and LED2[3:0] of LED register (address 0x07). One bit increment of LEDx[3:0] corresponds to +0.5 mA(typ).*

Table 13. Linear regulators

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
$I_{PLUSREV}$	Power fail reverse leak	V_{DCDC}=35 V, V_{DCDC}=D_{OUT}, V_{PLUS} = GND			10	µA
I_{OUT}	Regulator output capability	V3V3 or V5V	50			mA
R_{START_MIN}	Startup static capability		67			Ω
V_{V3V3}	Regulator output voltage	V3V3 0 mA<I_{OUT}<50 mA	3.0	3.3	3.6	V
V_{V5V}	Regulator output voltage	V5V 0 mA<I_{OUT}<50 mA	4.5	5.0	5.5	V
I_{PD5V}	Pull-down current of V5V pin		50	100	200	µA
V_{UV}	Undervoltage detect	see Table 29, V_{UV} <10V	UV_{SET}-1	UV_{SET}	UV_{SET}+1	V
		V_{UV} ≥10V	UV_{SET}-10%	UV_{SET}	UV_{SET}+10%	V

Table 14. DC-DC supply

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
V_{PLUS}	Supply voltage	V_{PLUS} > DC-DC target Output (see Table 31. DC-DC output voltage, V_{SET})			35	V
I_{OUT}	DC-DC Output current		50			mA
$\|V_{SET\_TOL}\|$	V_{SET} tolerance	see Table 31. DC-DC output voltage, V_{SET}	-10%	V_{SET_NOM}	+10%	V

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
t_{VSET}	V_{SET} step size			52		µs
Δt_{VSET}	V_{SET} range delay	$V_{SET\_MIN} \rightleftarrows V_{SET\_MAX}$	$7*t_{VSET\_MIN}$		$7*t_{VSET\_MAX}$	µs
R_{DCDC}	Output voltage load regulation	0-50mA			2	Ω
$I_{STARTUP}$	Startup current	From pin V_{PLUS}, See Section 16.3.1	50	80	140	mA
$V_{STARTUP}$	Startup voltage	On pin V_{DCDC}, See Section 16.3.1	7.5	8.0	8.5	V
$V_{VPLUSDCMIN}$	DC-DC operation start		7.0	8.0	9.0	V
f_{DCDC}	Operating frequency	see Table 30	-10%	f_{SET}	+10%	kHz
R_{HIGH}	High side resistance		3.3	6.6	20	Ω
R_{LOW}	Low side resistance		4.5	7.2	20	Ω
I_{LIMIT}	I_{LIMIT} in inductor		70		90	mA
R_{SHUNT}	Sense resistance		0.6	1	1.5	Ω

4 Startup

At startup, power is applied via the cable on V_{PLUS}. The embedded Power-On-Reset (POR) circuit ensures the proper startup of the L6364 with the output switches initially in a high impedance state. The device core of the L6364, including the control for the 5 V regulator, is supplied by the V3V3 supply.

The SPI communication logic is reset whenever SS='1' and is independent of the L6364 power on reset itself.

It is therefore possible to read the SPI register values even when the L6364 is in reset. In particular, the STATUS:RST bit is read as part of the STATUS byte on every SPI access.

This bit is cleared when the device is in reset, or when the device has been reset. This status information can be used as set out in Table 15 to determine the L6364 reset state, and also to react to unexpected reset conditions.

Table 15. L6364 Reset conditions

Device state	STATUS:RST	INT	Comment
Power-On-Reset (POR)	0	0	L6364 is in power on reset (checked at the start of the SPI access). Only the STATUS:RST bit is valid. The microcontroller may wait for a high level on INT before proceeding.
Device reset (post POR)	0	1	L6364 has been reset, and the INT line is forced high. Write STATUS:RST='1' to allow normal operation of the L6364.
Operation	1	X	Normal operation

The microcontroller should initialize the state of the internal registers to the desired values after reset.

5 SPI Communication

Internal registers (see Figure 17 and Figure 18 Register map) are provided to observe and control the L6364 state.

These register settings are read and written via the SPI interface, where the L6364 is the SPI slave. The operating voltage level for inputs and outputs on the SPI interface is set by the VDIG pin. This pin is typically be directly connected either to the V5V or V3V3 supplies.

The detailed timing diagram is shown in Figure 3 Data is shifted into an internal shift register from input MOSI on each rising SCK edge. Data is made available on pin MISO at each falling SCK edge. Note that the MISO line is only driven when the slave specific select line is SS='0', which allows other SPI slaves to share the same SPI bus.

The MSB of the address byte is a WR/RDn bit, where a '1' indicates that each byte is written to the registers.

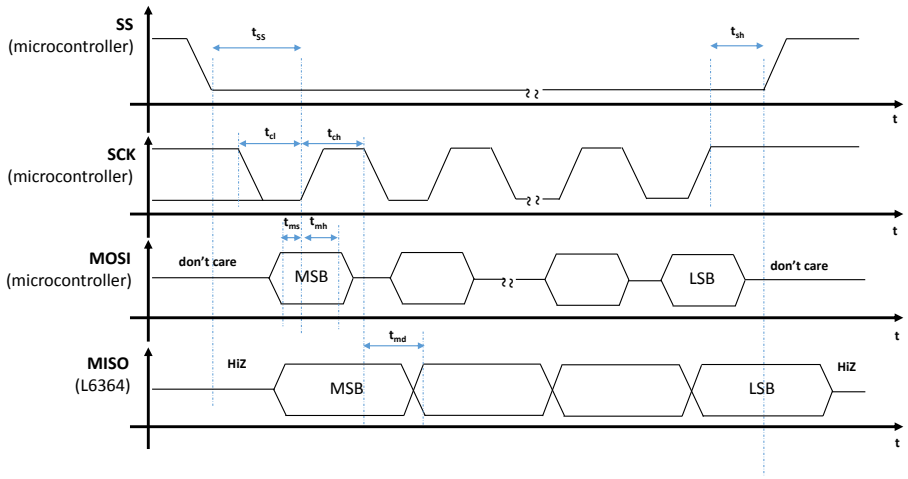
Valid data is always made available on the MISO line independent of the WR/RDn bit.

Where a register is written and read in the same operation, then the read value is the old register value. During read operations, the level of the MOSI line is ignored for the data bytes.

The byte sequence for data transmission is shown in Figure 4 Each transmission sequence consists of a falling SS edge which synchronizes transmission, followed by a target register address byte.

During the transmission of the address byte from the microcontroller to the L6364, the status register contents are sent from the L6364 to the microcontroller.

Figure 3. Register programming.



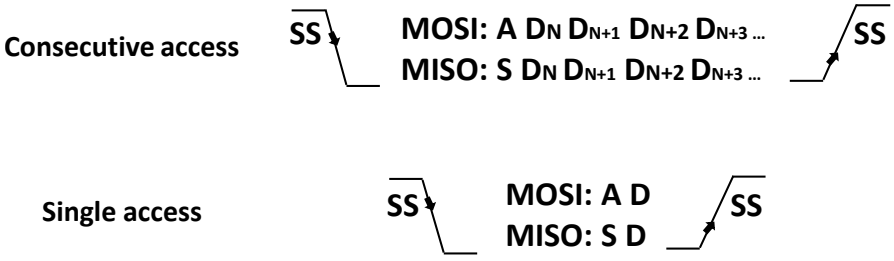
5.1 Multiple byte exchange

Multiple registers at consecutive addresses can be read or written by extending the access as shown in Figure 4; bytes are written on the rising SCK clock edge of the eighth bit of each byte.

With the WR/RDn bit set, a simultaneous read/write operation is started. Now, with a multiple byte exchange, it is possible to both read and write the values of multiple register bytes in one operation.

This is particularly useful with larger M-sequence types where there is limited time available for the SPI exchange.

Figure 4. **Single byte and sequential byte accesses**



KEY: *A: Address byte, D: Data byte, S: Status byte*

6 DIO pin

The DIO pin is a fully protected I/O which is driven or sampled independently via SPI. This pin may be operated in one of two modes:

- DIO mode: If the DCTL:DIO bit is set, then the DIO Line functions as a digital input output pin, which is independently driven according to the setting of the LS and HS bits in the DCTL register. Setting bit DCTL:IEN in this mode, enables a signal level change interrupt, informing the microcontroller that a level change has occurred on the DIO line.
- JOIN mode: If the DCTL:DIO bit is cleared, then the DIO/CQ outputs function together to provide a single, double drive strength, IO-Link conformal output. The outputs, DIO and CQ, must be externally shorted together. When in this mode, the DCTL:HS and DCTL:LS no longer have any effect on the output state.

6.1 DIO mode output control

In DIO mode there are two alternatives for controlling the pin output state: via SPI (DCTL:EXT reset) or directly via pin CTLD (DCTL:EXT set). Table 16 and s Table 17 show how the output is controlled in both cases respectively.

Table 16. DIO control via SPI-DCTL:EXT='0'

Mode	DCTL:HS	DCTL:LS	DIO Channel Output State
Off	0	0	HiZ
Low	0	1	0
High	1	0	1
Illegal	1	1	HiZ

If bit DCTL:EXT is set, bits DCTL:HS and DCTL:LS function as configuration bits, which configure the DIO output to be a PNP, NPN or Push-Pull driver.

Table 17. Direct DIO control via pin CTLD – DCTL:EXT='1'

			DIO Channel Output State	
Mode	DCTL:HS	DCTL:LS	CTLD='1'	CTLD='0'
Inactive	0	0	HiZ	HiZ
NPN	0	1	0	HiZ
PNP	1	0	1	HiZ
Push-Pull	1	1	1	0

The high- and low-side switches are identical and have an on-state resistance of R_{SW}. Any inactive switch acts as a Zener diode limiting the voltage on the DIO line to V_{ZEN} above V_{PLUS} (high-side switch), or V_{ZEN} below GND (low-side switch). This allows rapid switch-off for inductive loads.

The DIO data level is monitored for signals, filtering out pulses with a duration of less than (1/16) * T_{BIT}, see Table 5.

The decision threshold for the DIO data level is determined by the CFG:RF bit. Where this is '0', the IO-link standard absolute levels are used, and where the bit is '1' the threshold is referred to V_{PLUS}/1.8.

6.2 SIO mode control

In the SIOActive state, the high-side or low-side switches are switched according to the CCTL:HS and CCTL:LS bits. It is not legal to switch on both simultaneously, and this register setting disables both switches.

The high-side and low-side switches are identical, and have an on-state resistance of R_{SW}.

Any inactive switch acts as a Zener diode limiting the voltage on the CQ line to V_{ZEN} above V_{PLUS} (high-side switch), or V_{ZEN} below GND (low-side switch). This allows rapid switch-off for inductive loads.

7 IO-Link UART peripheral

The L6364 contains an IO-Link UART peripheral for bidirectional communication according to the IO-Link Standard.

The peripheral is controlled, and data is exchanged, via SPI register accesses. In an application where pins CQ and DIO are coupled together i.e. JOIN mode, then a reference to CQ in the following refers to the shorted pair.

7.1 Multi-octet mode

7.1.1 SIO Mode

Figure 5 shows the IO-Link UART peripheral state machine. When the CCTL:SIO bit is set, the L6364 is set to Single Input Output mode. In this mode the L6364 has the following states:

- **SIOActive**: The CQ line is driven according to the setting of the HS and LS bits of CCTL register.

  The internal UART does not run in this state and so master messages are only detected if a wake-up request from the master is received, which switches the L6364 to the SIOListen state. If the output is set to high impedance (CCTL:HS=LS='0'), then the L6364 can not receive a wake-up request from the master. It is therefore necessary to switch to IO-Link mode (CCTL:SIO='0') if communication detection is required with a high impedance output.

- **SIOListen**: The L6364 has experienced a short-circuit via a wake-up request from the master.

  Both high-side and low-side switches are off, and the restart timer is running. Transitions on the CQ line are read as data, and stored in the data buffer (FR0 to FR14 registers). If a complete, valid, master message is received, then the state changes to Transmit, an interrupt is generated and the restart timer is reset. If the timer expires, then the L6364 returns to the SIOActive state and the CQ line is driven again after the transmission.

7.1.2 IO-Link mode

At startup, and if the SIO bit is cleared, the L6364 enters IO-Link mode. In this mode the L6364 has the following states:

- **IOListen**: Transitions on the CQ line are read as data, and stored in the data buffers. Once a complete master message has been read, or an error is experienced in reception (e.g. bad parity, checksum or time-out), then the state changes to Transmit.

7.1.3 Transmit mode

Following reception of an IO-Link master message the L6364 enters the following state:

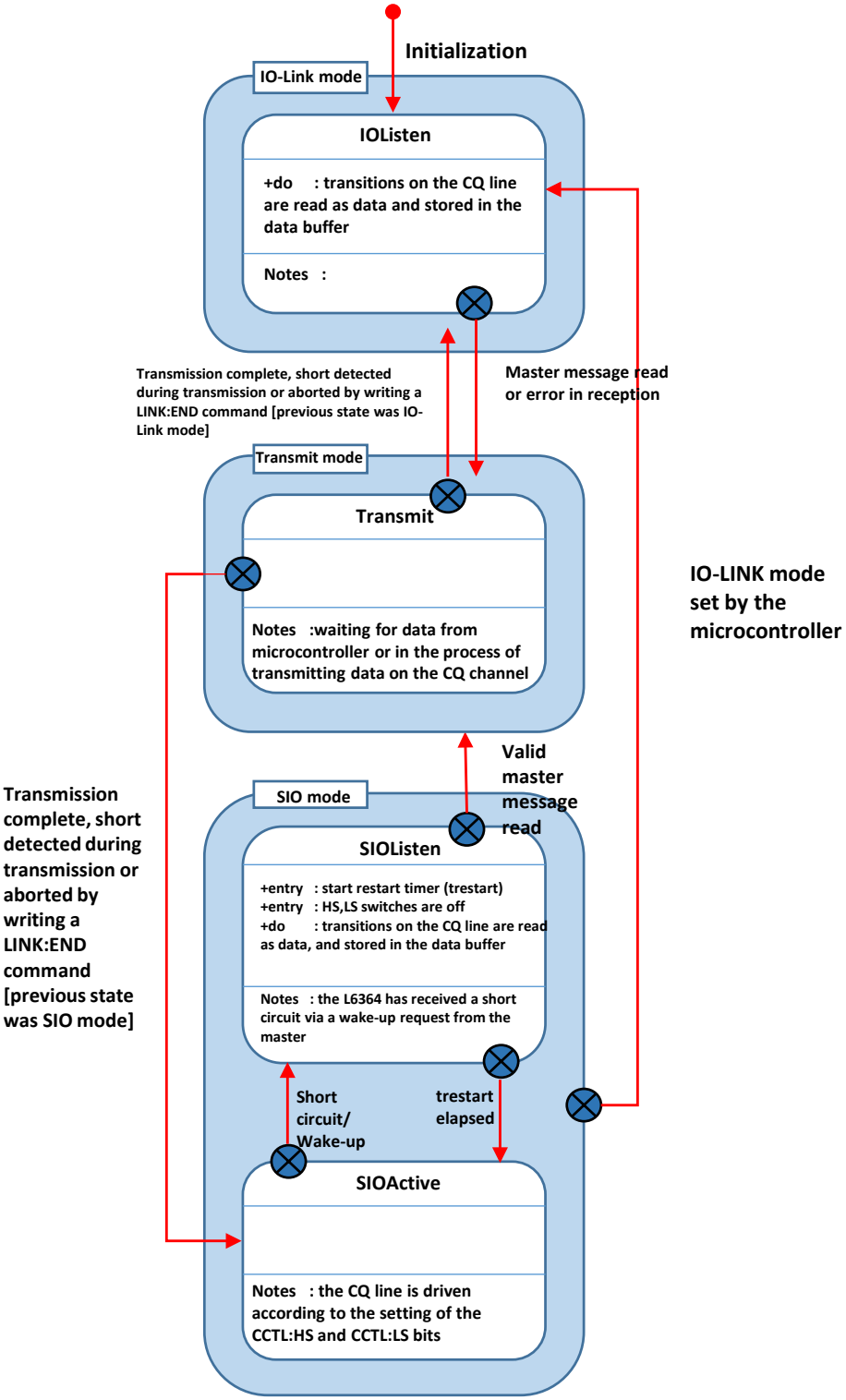
- **Transmit**: The L6364 is waiting on data from the microcontroller, or is in the process of transmitting data on the CQ channel. The L6364 reverts to IOListen or SIOActive on completion of the transmission, or if an abort is generated by the microcontroller by setting END bit in the LINK register.

  If the L6364 has entered Transmit from an SIO mode, the microcontroller would normally now set the L6364 to IO-Link mode, such that the L6364 continues to listen for further information from the master.

  If the L6364 experiences a short-circuit during Transmit, then the STATUS:SSC bit is set, and the L6364 returns to either IOListen or SIOListen.

7.1.4 IO-Link UART peripheral (Multi-octet mode) state machine

Figure 5. IO-Link UART peripheral state machine



7.1.5 Interrupt handling

The L6364 signals an event to the microcontroller using the INT pin, which is intended to be configured as a level sensitive interrupt.

7.1.6 Data interrupt handling

If the STATUS:DAT bit is read as active (high) on an SPI access, then the L6364 is halted in a WAIT condition and is waiting for either a LINK:END or LINK:SND command from the microcontroller.

While the L6364 is in the WAIT condition the interrupt pin (INT), the STATUS:INT bit and the STATUS:DAT bit remain active continuously.

Data can be read and written to the L6364 registers while in the WAIT condition.

Typically the LINK register and FR registers are accessed to read the incoming data, and the FR registers are written to set up the outgoing data. As the L6364 is halted, it doesn't generate further data interrupts in the WAIT condition.

When the microcontroller sends either a LINK:END or LINK:SND command, the interrupt pin (INT), the STATUS:INT bit and the data bit, STATUS:DAT, are cleared within 220 ns of the last SCK edge of the SPI write access.

If the microcontroller detects an active interrupt after the SPI access, or if the STATUS:DAT bit is read as active (high) on a subsequent SPI access, then new data is available.

The LINK register is duplicated as LINK2 at address 0xF to optimize sequential SPI access:

- a sequential SPI read can be used to read the LINK2 register and then the frame registers in one SPI operation.
- a sequential SPI write (including SND bit) can be used to write the LINK2 register and then the frame registers. Transmission starts once the FR0 register is written and the micro-controller must ensure that the subsequent registers have valid values before the start of transmission of the respective octets.

7.1.7 Short-circuit, overtemperature and undervoltage interrupt handling

The INT pin and the STATUS:INT bit are additionally active (high) if the last value of the short-circuit, undervoltage or overtemperature status bits communicated on the SPI is different to the current value.

The L6364 handles short-circuit and overtemperature autonomously and does not require a reaction from the microcontroller.

It is possible for these status bits to change at any time, and so the interrupt may be removed between entering the interrupt service routine and reading the status on the SPI.

The interrupt is removed during the next SPI access to the L6364. If an SPI access is made without checking the value of these bits, as is typical during processing of a data interrupt, it is normal to record the status values from the final access, or to explicitly add an extra SPI access.

7.1.8 Interrupt handler structure

The interrupt handler will typically have the following sequence:

read the L6364 status with a read access from the LINK register if (STATUS:DAT is active)

{

analyze the STATUS:CHK bit, read the FR registers and write an appropriate response into the FR registers

send LINK2:SND or LINK2:END as appropriate and write the response into the FR registers

};

update the microcontrollers copy of the short-circuit, undervoltage and overtemperature status based on the status bits received in the previous access. Take action if necessary.

7.1.9 Changing to and from SIO mode

The L6364 should be placed into IO-Link mode as soon as communication with the master is established.

Typically a switch from SIO mode (CCTL:SIO='1') to IO-Link mode (CCTL:SIO='0') is made during the WAIT condition when a valid message is detected from the master.

A switch from IO-Link mode to SIO mode is typically made shortly after the device response for the FALLBACK command has been sent. The switches themselves are, however, only activated by the microcontroller after the period defined in the IO-Link specification.

The L6364 may be switched from SIO mode to IO-Link mode at any time without disturbing data reception or transmission. A switch from IO-Link mode to SIO mode may disturb data reception if a master is in the process of transmitting, and the UART is therefore reset if this occurs.

7.1.10 SPI register writes outside interrupt service routines

The interrupt service routine typically accesses the SPI, and so it is necessary to avoid a collision between an interrupt service routine SPI access and any other SPI access made from the microcontroller.

Accessing the SPI clears a short-circuit or overtemperature interrupt, and so the received value of these bits must be recorded by the microcontroller.

If a function makes a number of sequential SPI accesses, then it is reasonable to ignore these status bits on all but the last access, and record the values read on this last access.

It is not necessary to check the STATUS:DAT bit outside the interrupt service routine, since the data interrupt remains active until the microcontroller responds.

7.2 Single octet UART mode

The L6364 supports an operating mode called Single octet UART mode, which performs a simplified data transfer function, transferring one octet at a time in either direction.

In this mode, M-sequence type recognition (MSEQ:M2CNT), the number of on-demand data octets (MSEQ:OD1, MSEQ:OD2) and checksum verification/generation are disabled and, therefore, must be realized by the microcontroller.

Note, that an exchange is always triggered by the master. It is not possible to transmit data without first receiving valid data. Figure 6 shows the single octet UART mode state machine. When the CCTL:SGL bit is set by the microcontroller, the L6364 is set to single octet UART mode.

7.2.1 Buffering

The FR0 register and the L6364 UART internal register together provide double buffering of data in receive and single buffering in transmit. In order to avoid buffer over- or under-runs it is necessary for the microcontroller to:

- read FR0 before the UART writes a new octet in Receive mode (delay ca. $11xT_{BIT}$), or
- write FR0 before the UART requires a new octet in Transmit mode (delay ca. $3xT_{BIT}$).

7.2.2 Receive mode

In Receive mode the L6364 has the following states:

- **Receive wait**: The L6364 has received a complete master octet via the CQ channel. A data interrupt is generated (STATUS:DAT='1') and the received octet is placed in the FR0 register.

  The microcontroller has access to the FR0 register and reads the received octet. The state changes to Receive Interim.

  The L6364 is now waiting for a response from the microcontroller, which either writes LINK:END to continue receiving, or FR0 to initiate sending. (A LINK:END should not be sent after receiving the last octet.)

  The UART continues to run in this state receiving the following frame. A buffer over-run results if the microcontroller does not read FR0 before the frame completes.

  A UART frame is 11 bits, which at 230.4kBaud gives a period of 47µs for the two SPI accesses, each of 16 bits. At 4 MHz SPI this corresponds to an SPI delay of 4 µs.

  Error conditions: parity error, stop bit, time-out (more than $4xT_{BIT}$ waiting for the next UART frame on the CQ line), or buffer under-run are signaled with a data interrupt (STATUS:DAT='1') with additionally STATUS:CHK='1'.

  The microcontroller should respond by writing LINK:END and discarding any received octets. The master stops sending after the last master octet and so a time-out is generally detected by the L6364 in the delay while the microcontroller is preparing the response.

  The condition is held internally in the L6364 and discarded by the L6364 when FR0 is written by the microcontroller, initiating transmission. The timeout is therefore not reported to the microcontroller in this case.
- **Receive interim**: The UART receives data on the CQ line and copies this to the FR0 register, switching to Receive wait on completion.

Once the expected number of octets is received, the microcontroller initiates sending by writing the first octet in the response M-sequence to FR0, thereby switching the L6364 to Transmit mode (see Section 7.2.3). (In single octet UART mode the equivalent of a LINK:SND command is achieved by writing to FR0).

In SIOListen mode a received UART frame is only reported if the parity and stop bits are correct. The microcontroller must switch from SIO mode to IO-Link mode after reception of a valid UART frame before responding with LINK:END, otherwise the L6364 returns to SIO mode conflicting with the further master transmission.

7.2.3 Transmit mode

Transmit mode is entered when the microcontroller writes FR0 while the L6364 is in the Receive wait state.

The UART reads this value from the FR0 register, emptying the buffer, and starts transmitting. The L6364 enters the Transmit wait state.

The L6364 provides a single octet data buffer and requests further data whenever this buffer is empty, including during the transmission of the previous octet. It is only necessary to ensure that this buffer is refilled before the UART needs to send the next octet.

The maximum allowed time between the starts of two subsequent frames on IO-Link is 11 T_{BIT} frame + 3 T_{BIT} pause = 14 T_{BIT}, which at 230.4kBaud gives a period of 60 µs for the 16 bit SPI access. At 4 MHz SPI this corresponds to an SPI delay of 4 µs.

In Transmit mode the L6364 has the following states:

- **Transmit wait**: The L6364 requests a new octet by sending a data interrupt (STATUS:DAT='1').

  The L6364 is waiting for a response from the microcontroller, which either writes FR0 with a new octet to continue transmission, or LINK:END to terminate transmission.
- **Transmitting (buffer empty)**: The UART sends the current octet.

  A further response is requested from the microcontroller, by sending a data interrupt (STATUS:DAT='1'). If the microcontroller provides a further octet, this is placed in the buffer and the state changes to Transmitting (buffer full), if the microcontroller writes LINK:END, then the state changes to Transmitting (terminating).

  If the microcontroller does not provide an octet before the UART transmission completes, then the state changes to Transmit wait.
- **Transmitting (buffer full)**: The UART sends the current octet. On completion, it sources the next octet from the buffer, and the state changes to Transmitting (buffer empty).
- **Transmitting (terminating)**: The UART sends the current octet. On completion, the PHY returns to idle.

7.2.4 Timing errors in transmit

The microcontroller can cause a timing error in Transmit mode if the delay in response is too long. These errors are not monitored by the L6364. A minimum inter-frame time delay of 1xT_{BIT} is, however, guaranteed by the L6364.

7.2.5 Error condition in transmit

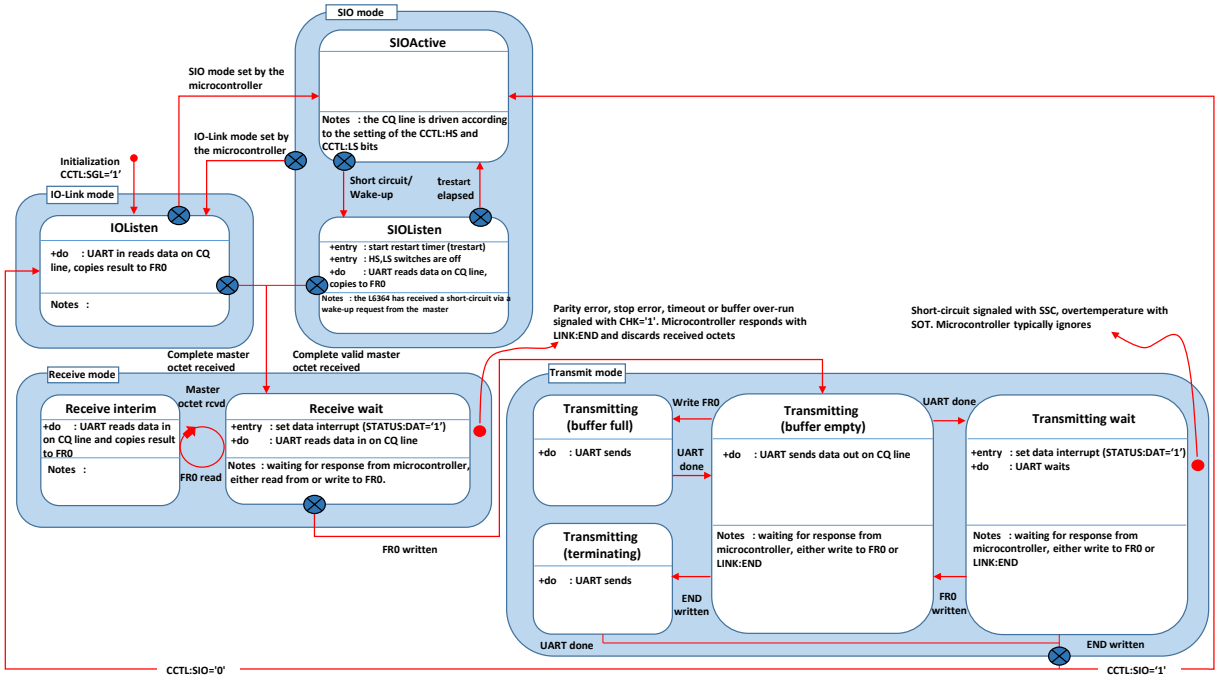
Error conditions are reported to the microcontroller as either short-circuit (STATUS:SSC='1', reported following a delay of t_{RETRY}), or overtemperature (STATUS:SOT='1').

The conditions are handled autonomously by the L6364 and no intervention by the microcontroller is necessary. The normal data flow is preserved and the L6364 requests further octets from the microcontroller as if the error were not present.

These octets are silently dropped and no attempt is made to transmit them. Under error conditions, then transmission may be terminated by the microcontroller using LINK:END='1'.

7.2.6 Single octet UART mode state machine

Figure 6. Single octet UART mode state diagram



7.2.7 Synchronization in single octet UART mode

The L6364 uses a PLL (phase-locked loop) to continuously lock the UART receive and transmit frequency to the master frequency.

A few octet values (00h, 80h, e0h, f8h and feh) do not provide information which can be used to correct the PLL frequency, and a continuous sequence of these values could prevent the PLL performing frequency tracking for some time.

In IO-Link operation, however, it is not possible to create such M-sequences as the defined format of the M-sequence, and in particular the checksum, guards against this.

A continuous sequence of these octets is possible when the single octet UART mode is used in a proprietary mode, eg. for code download.

In this case, the insertion of a synchronization octet (aa_h) at least every 75 ms is required, taking into account a worst case dissipation change (1W) in combination with a worst case oscillator temperature drift. The interval of 75 ms is equivalent to 240 octets at 38.4kBaud assuming an inter-frame delay of 1 bit. We recommend the insertion of a synchronization octet every 32 octets.

7.3 Transparent mode

The L6364 supports an operating mode for transparent communication of UART frames.

In this mode, the frames are received and transmitted from a UART peripheral in the microcontroller, and the function of the DUAL PHY device is reduced to that of a physical level converter.

This mode is supported by dual use of the MOSI and MISO pins, maintaining the low overall pin-count and a restricted use of microcontroller resources.

Transparent mode is entered by setting the CCTL:TRNS register bit to '1' via the SPI. In this mode the IO-Link state machine in the L6364 and the PLL are placed in reset.

The interrupt line and status monitoring for reset, short-circuit, overtemperature and undervoltage events continue to function.

7.3.1 Pin functions in transparent mode

In transparent mode, the MOSI and MISO pins are used for both SPI communication, and for the transparent path. The SS pin controls the use of the MOSI and MISO pins, according to Table 18.

Table 18. Pin dual use in transparent mode

	SPI comm's	Transparent path	MOSI	MISO
SS='0'	SPI comm's active	CQ output switch control frozen	SPI data in	SPI data out
SS='1'	SPI comm's frozen	Transparent path active	CQ output switch control	Filtered CQ line level

An SPI communication in transparent mode is shown in Figure 7. Initially the L6364 is driving the CQ line; an SPI exchange is then conducted in which the L6364 is instructed to stop driving the line, and finally the IO-Link master drives the CQ line.

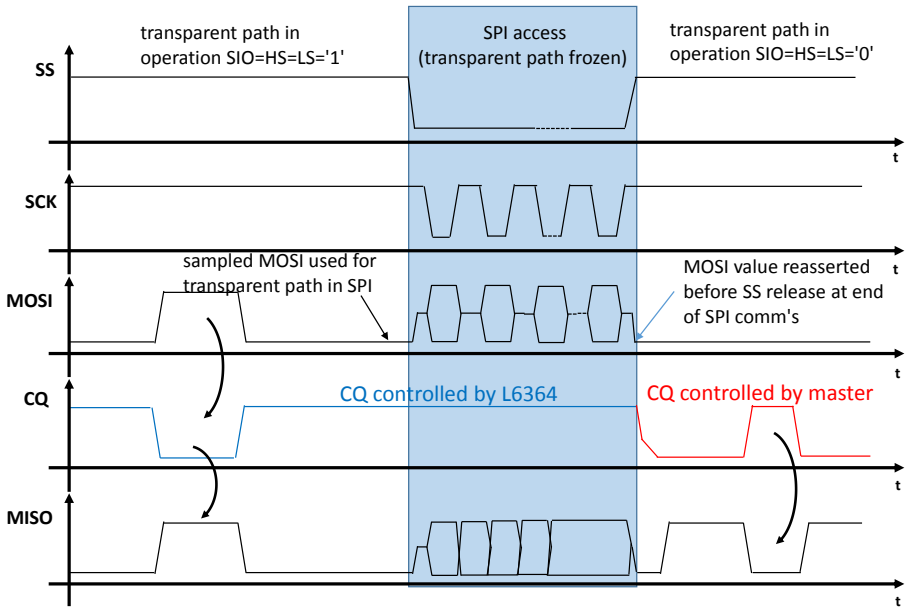
Typically the microcontroller SPI access routine records the MOSI level in use before setting SS='0' to start an SPI access, and assert this value again on the MOSI line before setting SS='1'.

The microcontroller should preset the MOSI pin to the required level before the first SPI access enabling transparent mode.

Support for this may, however, be automatic depending on the microcontroller.

The SPI connection to the L6364 is not suitable for a bus connection of multiple SPI slaves in transparent mode as the MOSI line is permanently driven.

Figure 7. Illustration of operation in transparent mode



7.4 Transparent mode output path

With SS='1', the level of the MOSI pin controls the output switches according to the SIO, HS and LS bit settings as shown in Table 19. Where SS='0' for SPI access the level latched on the MOSI line is frozen, and used in the place of the MOSI line itself.

The CCTL:HS and CCTL:LS bits function as enables for the high-side and low-side switches respectively, and select operation as a high-side, low-side or push-pull device.

Note that the logical path from MOSI to CQ is inverting.

Table 19. **Transparent mode operation**

CCTL:SIO	CCTL:HS	CCTL:LS	Operation	Short-circuit
1	0	0	SIOListen operation	Short reported after retry
1	0	1	Low-side SIO operation	
1	1	0	High-side SIO operation	
1	1	1	Push-pull SIO operation	
0	0	0	IOListen operation	Short timers reset
0	0	1	Do not use	
0	1	0	Do not use	
0	1	1	Push-pull IO-Link operation	Short reported immediately

In transparent SIO operation (CCTL:TRNS='1', CCTL:SIO='1') a short is only reported after N retries, see t_{RETRY}, which is suitable to indicate the presence of a valid IO-Link wake-up pulse.

In transparent IO-Link operation (CCTL:TRNS='1', CCTL:SIO='0'), a short is reported immediately after t_{SHORT}.

In both cases the device attempts to drive the line again after t_{RETRY} and then $t_{RESTART}$ without intervention from the microcontroller.

The output switches are disabled while a short is reported, protecting the device from excessive dissipation.

The short condition and associated internal timers can be reset by setting IOListen operation (CCTL:TRNS='1', CCTL:SIO=CCTL:HS=CCTL:LS='0'), which allows switching to push-pull IO-Link operation after valid data has been received.

Following a cleared short condition, a new driving operation should only be selected after receiving valid IO-Link data or waiting for at least $t_{RESTART}$.

7.4.1 Transparent mode input path

With SS='1' in transparent mode, the level of the MISO line is the inverted level of the CQ signal. The signal is filtered with a constant delay filter, (1/16) * T_{BIT}, see Table 5, to remove line glitches.

7.4.2 Leaving transparent mode

Transparent mode is left by clearing the CCTL:TRNS register bit to '0' via the SPI.

8 IO-Link physical layer

8.1 UART frame

Table 20. UART frame definition

Bit#	Significance	Level
1	START	0
2	LSB	b0
3		b1
4		b2
5		b3
6		b4
7		b5
8		b6
9	MSB	b7
10	PARITY	P
11	STOP	1

A logic '1' is transmitted as a low level on the CQ line, and a logic '0' is transmitted as a high level on the line. The idle state for the CQ line is low.

Even parity is used, that is, there is always an even number of logical '1' bits in the 9 bit concatenation of the data bits b[7:0] and the parity bit.

8.2 M-sequence interpretation

The data direction is derived from the MSB of the first octet of the master message, M-sequence control (MC), where a ‘1’ denotes a read operation and a '0' a write.

Table 21. M-sequence control (MC) octet

MSB							LSB
R/W	Comm chan.		Address				

The M-sequence type is derived from bits [7:6] of the second octet of the master message, “Checksum/ Msequence type” (CKT), which have permissible values of 2'b00, 2'b01, or 2'b10, and denotes whether the structure of the message is of Type 0, Type 1 or Type 2.

Table 22. Checksum/M-sequence type (CKT) octet

MSB							LSB
M-seq. type		Checksum					

The total length of the received M-sequence is determined according to Table 23 and is dependent on the M-sequence type and on the transfer direction (READ or WRITE).

Table 23. Receive M-sequence lengths

	CKT:M-seq.type [7:6]	Received M-Sequence length	
		READ, MC:R/W = '1'	WRITE, MC:R/W = '0'
Type 0	00	2 octet	3 octet
Type 1	01	2 octet	2 octet + f(OD1)*
Type 2	10	M2CNT	M2CNT+ f(OD2)

f(OD1), f(OD2) and M2CNT are used to configure the L6364 for M-Sequence reception and are configured through register MSEQ as follows:

- f(OD1), f(OD2): defines the received number of on-demand octets, where support is only provided for data widths of 1, 2 and 8 octets and not 32. The values are determined from MSEQ:OD1[1:0] for type 1 sequences and MSEQ:OD2[1:0] for type 2 sequences according to Table 24.

Table 24. Permissible values of MSEQ:OD1 and MSEQ:OD2

MSEQ:OD1[1:0]	f(OD1) (On-demand data)		MSEQ:OD2[1:0]	f(OD2) (On-demand data)
00	Illegal*		00	1 octet
01	2 octet		01	2 octet
10	8 octet		10	8 octet

- M2CNT: defines the expected octet count on a read operation. Its value corresponds to the value of field MSEQ:M2CNT[3:0]

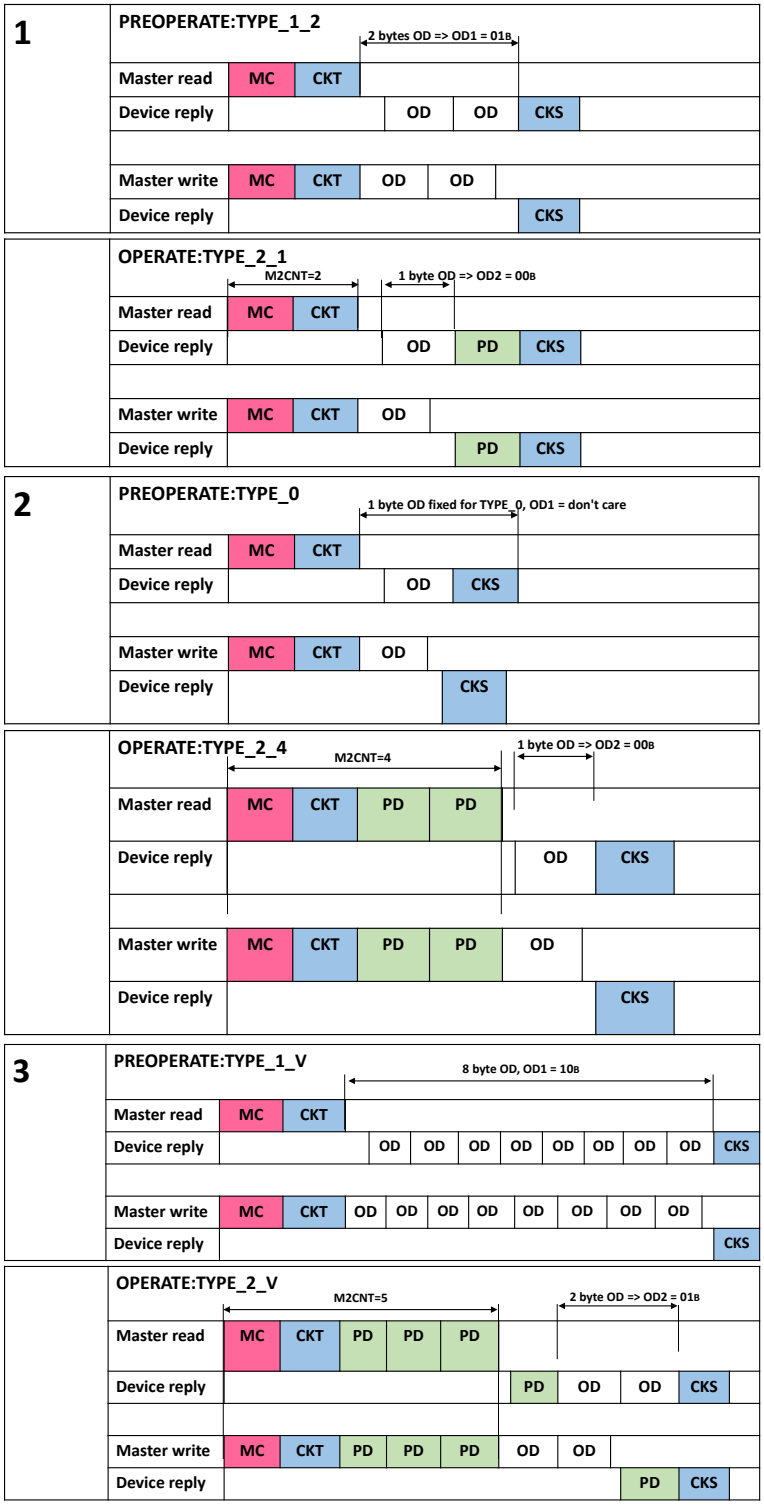
The total data buffer size is 15 octets. If an M-sequence of a length greater than this is required for reception or transmission, then the single octet access mode should be used (see Section 7.2).

*A setting of MSEQ:OD1[1:0]=00 is used for backwards compatibility. In this case M2CNT + f(OD2) defines the length of received type 1 M-sequences.

8.2.1 Example setting

Table 25 shows examples to illustrate the correct register settings for M2CNT, OD1 and OD2 for different combinations of PREOPERATE and OPERATE M-sequences.

Table 25. Example M2CNT, OD1 and OD2 registers setting



8.3 Checksum calculation and verification

The checksum for an out-going message is calculated by the L6364, by logically exclusively OR'ing all LINK:CNT octets of the message, with a starting value of 0x52h.

For this calculation the written value of the Checksum register should be zero. The Checksum is then compacted from 8 to 6 bits using the algorithm of Table 26:

Table 26. Checksum compaction

Bit	Calculation
C[5]	D[7] xor D[5] xor D[3] xor D[1]
C[4]	D[6] xor D[4] xor D[2] xor D[0]
C[3]	D[7] xor D[6]
C[2]	D[5] xor D[4]
C[1]	D[3] xor D[2]
C[0]	D[1] xor D[0]

The L6364 then inserts this 6-bit checksum into the lower bits of the last octet sent (“Checksum/status octet”).

Table 27. Checksum/status (CKS) octet

MSB							LSB
Event flag	PD Invalid	Checksum					

The L6364 calculates the expected checksum for an incoming message, by exclusively OR'ing the octets of the message, with a starting value of 0x52h.

For this calculation the Checksum/M-sequence type (CKT) octet is used, but with all of the bits of the Checksum field set to zero.

The calculated and expected checksum are compared and STATUS:CHK is set accordingly.

8.4 Data signal receive

The baud rate for signal reception is set by the CFG:BD bit. Both 38.4.4kBaud and 230.4kBaud are supported. The CQ data level is monitored for signals, filtering out pulses with a duration of less than(1/16) * T_{BIT}, see Table 5. The decision threshold for the CQ data level is determined by the CFG:RF bit.

Where this is '0', the IO-Link standard absolute levels are used, and where the bit is '1' the threshold is referred to VPLUS/2. The first transition is the start reference of the frame. After this, data is sampled at the center of each bit time. Bits are read into the data buffer, removing the start and stop bits. The fill level is recorded in the LINK:CNT field.

Once the expected number of UART frames have been read, the checksum and parity bits for the message are checked, and the STATUS:CHK bit set appropriately. The STATUS:DAT status bit is set, and an interrupt is generated. Consecutive UART frames are expected from the master within a period of 4xT_{BIT}. If this time is exceeded, then both STATUS:DAT and STATUS:CHK bits are set and an interrupt is generated.

The L6364 then enters the Transmit state and waits for the microcontroller to read the data and prepare a return message, signaling completion by writing a '1' to either the LINK:SND or LINK:END register bits.

8.5 Data output

The baud rate for transmission is set by the CFG:BD bit. Both 38.4.4k Baud and 230.4k Baud are supported. The number of message octets for transmission are written into the LINK:CNT field and sent following writing bit LINK:SND. The START, STOP and PARITY bits are appended to create the UART frames, and the checksum calculated and stuffed in the message.

The data is sent by using push-pull operation of the output switches. Writing either the LINK:SND or LINK:END bit clears the STATUS:DAT and STATUS:CHK status flags. The data output is synchronized using the internal PLL clock.

As defined in the IO-Link specification v1.1, the device has a maximum of $10xT_{BIT}$ periods to process the incoming message and prepare the response. A delay of up to $T_{BIT}/16$ can be incurred in the L6364 due to synchronization with the internal PLL clock, leaving the microcontroller slightly less than $10xT_{BIT}$ to respond.

8.6 Clock recovery

The L6364 has an internal RC clock with a nominal frequency of f_{CK}. The filtered data line is monitored for transitions while in the IOListen and SIOListen states.

When a first rising edge is seen, the internal PLL clock phase is aligned to the incoming data. The PLL clock corrects its operational frequency on the detection of further rising edges.

See Section 7.2.7 regarding detailed operation in single octet mode. The clock correction has a resolution of 0.4%(TYP) and a stability of 1%(MAX) over the duration of a message.

9 Short-circuit detection

In the case of a short-circuit or a wake-up request from the master, the CQ, or DIO-current exceeds the set short-circuit threshold. When this occurs continuously for a period longer than t_{SHORT}, the output transistors for the affected output are switched off.

In IO-Link mode, the event is signaled immediately to the microcontroller via the STATUS:SSC bit and an interrupt is generated. With CQ in SIO mode or with DIO in independent mode, a number of retries, N_{RETRY}, are attempted with a delay of t_{RETRY}. If these are unsuccessful then the event is signaled to the microcontroller via the STATUS:SSC bit and an interrupt is generated. A restart timer is started, with period $t_{RESTART}$.

If this timer elapses without intervention by the microcontroller or without reception of a valid IO-Link message, then the L6364 attempts to drive the line again. In the event of a continued short-circuit, this cycle repeats indefinitely.

The short-circuit current thresholds are set by CCTL:SCT[2:0] and DCTL:SCT[2:0]. Where JOIN mode is requested, the DCTL:SCT[2:0], DCTL:HS and DCTL:LS bits no longer have any effect on the output state or short-circuit detection.

Table 28. DC short-circuit threshold current, ISET, CQ and DIO

CCTL:SCT, DCTL:SCT	Threshold DIO/SIO	Threshold JOIN mode	CCTL:SCT, DCTL:SCT	Threshold DIO/SIO	Threshold JOIN mode
decimal	(mA)	(mA)	decimal	(mA)	(mA)
4	110	220	0	190	380
5	130	260	1	210	420
6	150	300	2	230	460
7	170	340	3	250	500

10 Maximum current output

The switches have an independent saturation current of I_{SAT}, and do not draw more current than this. If, however, the CQ and DIO pins are configured to create a single output (JOIN mode), then the saturation current in this case is $2xI_{SAT}$.

The power supply must be able to supply this current for the duration T_{SHORT} to prevent a supply voltage drop on V_{PLUS}.

11 Undervoltage detection

If the voltage on the VP_{LUS} is below the V_{UV} threshold, then the status bit UV is set. An interrupt is generated if this status is different to the status reported in the last SPI exchange.

The undervoltage thresholds are set by CFG:UVT[2:0].

Table 29. Undervoltage threshold

CFG:UVT decimal	Threshold (V)	CFG:UVT decimal	Threshold (V)
0	15.0	4	10.5
1	14.0	5	8.5
2	13.0	6	7.5
3	12.0	7	6.0

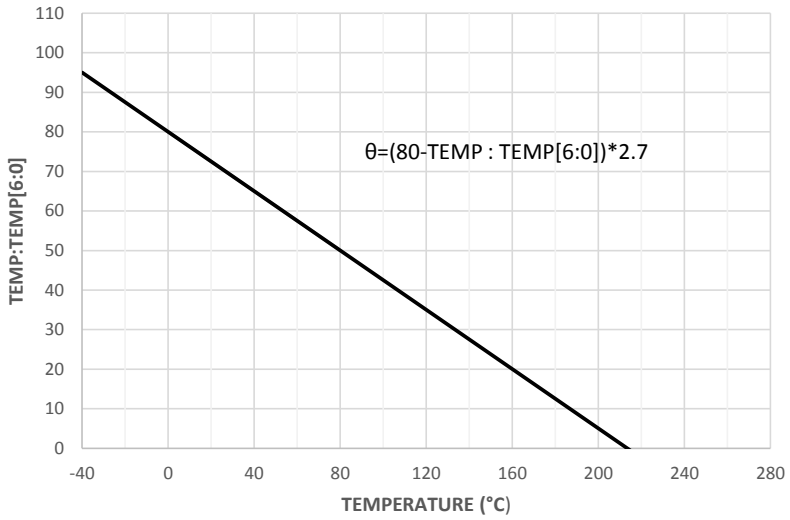
12 Short term power loss

If the supply on the V_{PLUS} fails then reverse current from V3V3 to V_{PLUS} and from V5V to V_{PLUS} is blocked. A residual leakage current of $I_{PLUSREV}$ may still flow in this time. Appropriate dimensioning of the capacitors C_{V3V3} and C_{V5V} can be used to maintain the power supply during this event.

13 Temperature measurement

The measured temperature in Celsius can be read from the L6364 from the TEMP:TEMP[6:0] register. The temperature is given as shown in Figure 8.

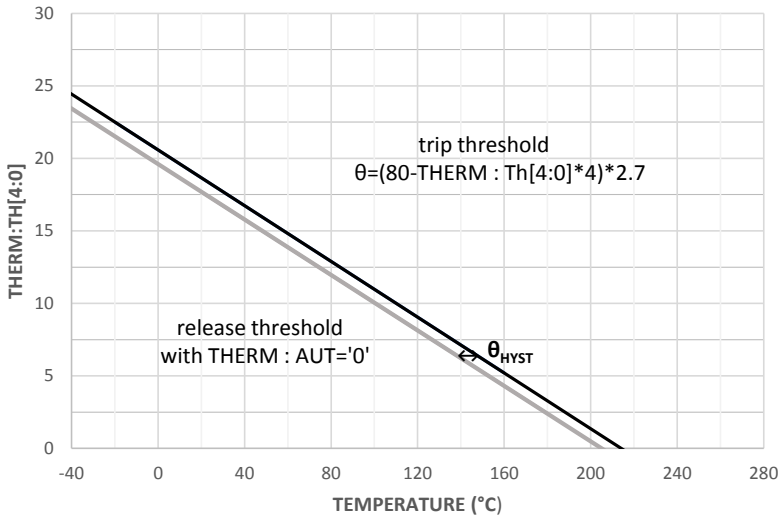
Figure 8. L6364 temperature measurement



14 Thermal shutdown

The STATUS:SOT status bit is a filtered version of the output of the temperature sensor. When the L6364 temperature exceeds the threshold this bit is set to '1', when the temperature is below the threshold the bit is set to '0'. The trip threshold is determined by the set-point in register THERM:TH[4:0] as shown in Figure 9.

Figure 9. L6364 thermal shutdown configuration



If the trip threshold is exceeded, the output switches are disabled, the event is signaled to the microcontroller via the status register (STATUS:SOT) and an interrupt is generated.

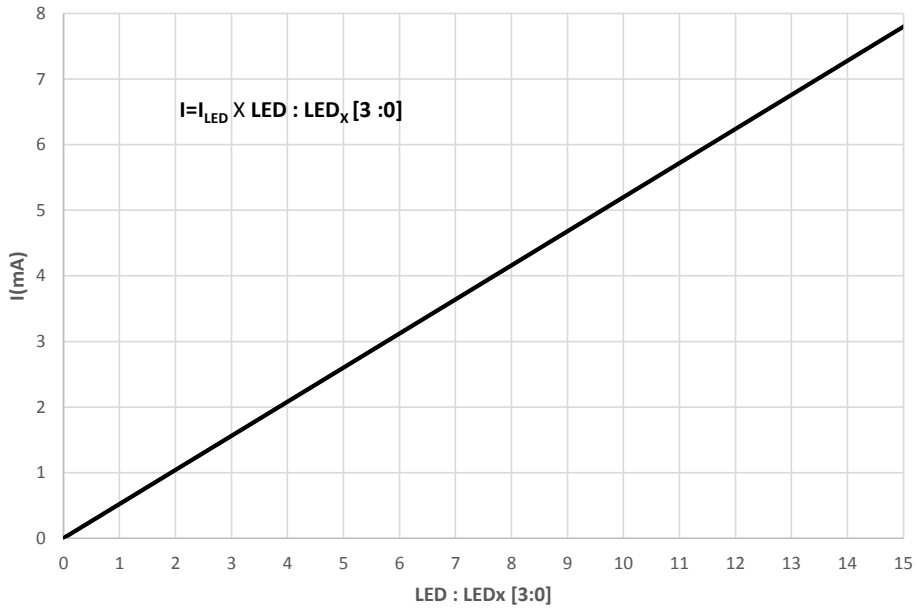
14.1 Automatic operation

If the THERM:AUT bit is '0' and a temperature in excess of the set point is reached, then the threshold is automatically moved to a release threshold Θ_{HYST} below the set point. When the temperature falls below this release threshold, the L6364 returns to a normal operating state and returns the threshold to the original level.

15 LED outputs

Two current controlled outputs are provided to generate an LED current up to 8 mA. The nominal LED current is defined by the settings of the LED:LED1 and LED:LED2 fields.

Figure 10. L6364 LED currents



16 DC-DC converter

16.1 Converter configuration

The L6364 includes a DC-DC buck converter, which operates at a frequency configured by register DCDC:FSET[2:0], shown in Table 30. Irregular frequency steps have been carefully chosen so to avoid simple fractional multiples, such that it is possible to choose a controller frequency which does not interfere with a given sensor frequency.

Table 30. DC-DC converter nominal operating frequency, F_{SET}

DCDC:FSET	Frequency	DCDC:FSET	Frequency
	(kHz)		(kHz)
4	500	0	1000
5	625	1	1250
6	710	2	1670
7	830	3	2000

The output voltage, VDCDC, is configured by DCDC:VSET[2:0], shown in Table 31. Note that where operation of the 5.0V linear regulator is required, the VDCDC output voltage must be configured to be at least $V_{DCDC\_5V\_MIN}$.

Table 31. DC-DC output voltage, V_{SET}

DCDC:VSET	Target output	DCDC:VSET	target output
	(V)		(V)
0	5.0	4	7.8
1	5.6	5(1)	8.6
2	6.1	6	9.6
3	6.8	7	10.5

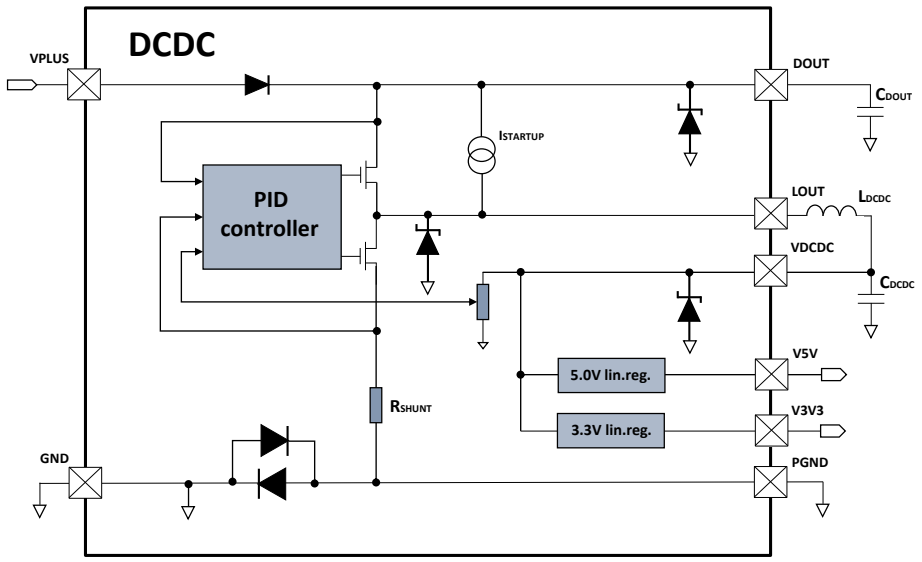
1. *Default value following reset.*

Changes to the output voltage via V_{SET} are executed in steps, with a delay of t_{VSET} for each step between $VSET_{MIN}$ and $VSET_{MAX}$. This minimizes any over- or undershoot on VDCDC as the output voltage approaches the target value. This implies that a maximum delay of Δt_{VSET} can occur between this range. If the DC-DC converter is not required, the pin DOUT is externally shorted to pin VDCDC.

16.2 Converter architecture

The buck converter consists of two internal MOS switches (PMOS and NMOS), an external capacitor, C_{DCDC}, and an inductor L_{DCDC}. The switches operate in anti-phase and, assuming no resistive losses, the output voltage (V_{DCDC}) is equal to the duty ratio of the high-side switch multiplied by the input voltage (V_{PLUS}).

Figure 11. **Block diagram of DC-DC converter**



This block also includes a sense resistor to measure the inductor current, R_{SHUNT}, a series diode to prevent conduction during reverse polarization and protection diodes to conduct residual inductor currents whenever switching ceases.

The high-side switch is activated at the start of each cycle, and remains on for a length of time determined by the PID controller. This time is further limited by the time T_{LIMIT} which is determined by the input voltage and restricts the coil current increase in any one cycle.

If the coil current exceeds the current threshold I_{LIMIT} at the start of the cycle, then activation of the high-side is completely suppressed.

The block monitors the voltage V_{DCDC} and the input voltage VPLUS.

16.3 Converter operation

16.3.1 Startup

The converter operates only when the following operating conditions are met:

- $V(_{V3V3})>V_{POR}$ - bandgap stable
- $V(_{VPLUS})>V_{DCMIN}$ - oscillator toggling
- $V(_{VPLUS})>V_{PLUSDCMIN}$

Operation outside these conditions is prevented to protect the IC and the surrounding circuit.

Initially the converter is in a STARTUP state. In this state an internal current source attempts to source a current $I_{STARTUP}$ from pin DOUT to pin L_{OUT}.

Where L_{OUT} is connected to V_{DCDC} by an inductor, V_{DCDC} is pulled up by this current. V_{DCDC} rises until it reaches voltage $V_{STARTUP}$, where the source current is then regulated to maintain voltage V_{DCDC} voltage at $V_{STARTUP}$. The converter remains in the STARTUP state until the operating conditions are met.

Bias is provided either by a HV bias circuit where the IC is in reset $V(V3V3)<V_{POR}$, or by an LV bias circuit once V3V3 is available. During the overlap period, the bias currents are doubled.

16.3.2 Entry to operation

Once the operating conditions are met, or when the DCDC:DIS bit is reset, then the converter passes through an ARM state for 1 ms before starting operation. The switch controls are powered this state, but set to off.

16.3.3 Leaving operation

If the operating conditions are no longer met, then the converter passes back through the ARM state to the STARTUP state. If, however, the DCDC:DIS bit is set, then the converter passes back through the ARM state to the SLEEP state. On leaving operation, any residual energy in the coil is conducted to V_{DCDC} via the protection diode between L_{OUT} and P_{GND}.

16.3.4 SLEEP state

The SLEEP state is reached by setting the DCDC:DIS bit via the microcontroller. In the SLEEP state no current is drawn by the DCDC converter on V_{PLUS} or V3V3, and the switch control blocks are depowered. The SLEEP state is left by resetting the DCDC:DIS bit, or during a L6364 reset, that is when $V(V3V3)<V_{POR}$.

16.3.5 BYPASS state

The BYPASS state is equivalent to the STARTUP state, and is reached after time T_{BYP_EN} by setting the DCDC:BYP bit via the microcontroller. In this mode, power is provided via the inductor and linear regulator.

In this mode, the $I_{STARTUP}$ current source is permanently enabled and the voltage on V_{DCDC} is held at $V_{STARTUP}$. Power to the devices on the V3V3 or V5V pins is now provided via the inductor and linear regulators. Leaving the BYPASS state is achieved by clearing the DCDC:BYP bit, whereby normal operation of the DC-DC converter resumes after time T_{BYP_DIS}.

This operation mode can be used if a device is operated at times in a low current consumption state, or suppression of converter switching noise is required for a temporary period.

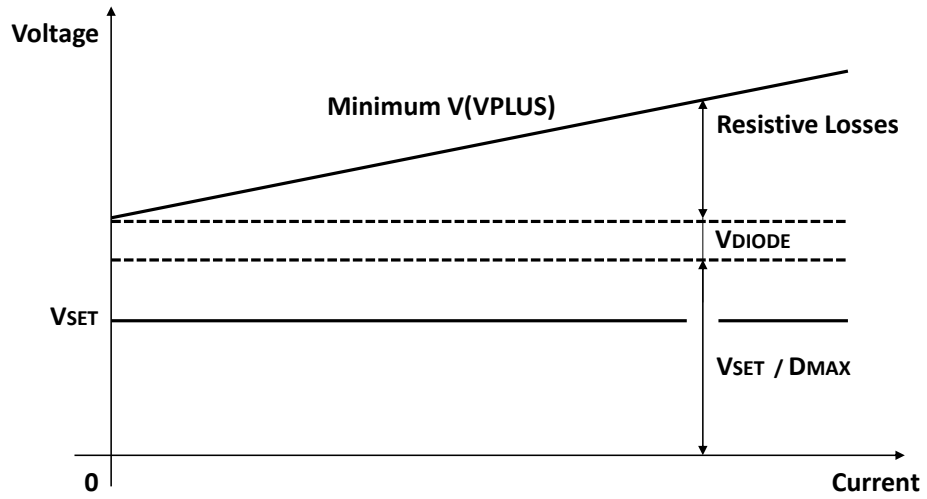
16.4 Converter external component consideration

16.4.1 Minimum supply voltage

The DC-DC converter has a minimum off-time per cycle, which leads to a maximum duty of:

$$D_{MAX}=1-150\ ns \times f_{SET}\ ;\ eg.\ at\ f_{SET}=1MHz,\ D_{MAX}=0.85$$

Figure 12. Minimum supply voltage



The supply voltage (VPLUS) required to reach a nominal output voltage (VSET) is given by:

$$V\ (VPLUS)= V_{SET} / D_{MAX} + V_{DIODE} + I_{OUT} [R_{COIL} / D_{MAX} + R_{HIGH} + (1/D_{MAX} - 1)(R_{SHUNT} + R_{LOW})]$$

For VS_{ET}=8.6V, V_{DIODE}=1V, I_{OUT}=50mA, R_{COIL}=2Ω, R_{HIGH}=R_{LOW}=20Ω, R_{SHUNT}= 1.5Ω, D_{MAX}=90%, a supply voltage of 11.80 V is required ensure that the nominal set voltage can be reached for all devices over the entire temperature range.

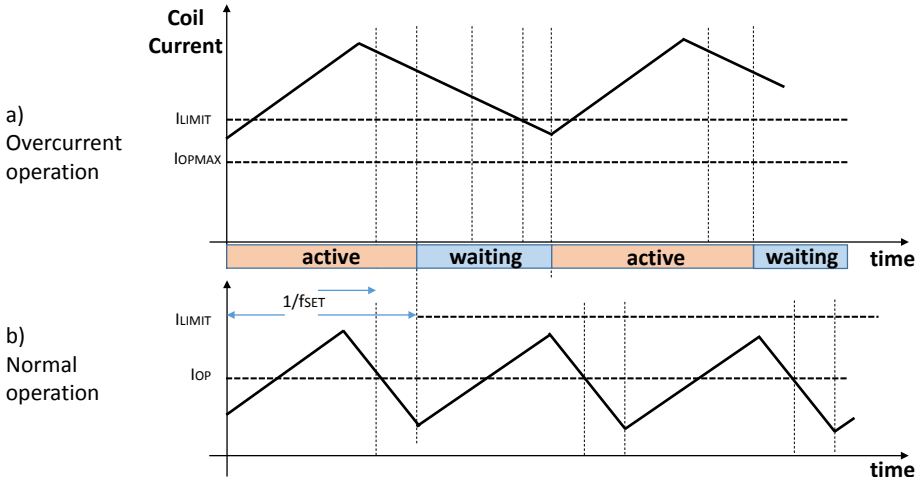
Note: At very low supply voltages, where the duty cycle approaches D_{MAX}, an increased ripple on the VDCDC supply may occur.

16.4.2 Coil current limitation protection

Where the coil current exceeds I_{LIMIT} at the start of a cycle, that cycle is aborted. The current is checked again every 200 ns and a normal cycle is started once the coil current is below I_{LIMIT}.

This results in a constant current output behavior with a variable frequency switching (see Figure 13). The operating current and external components should be chosen to avoid this behavior under normal conditions.

Figure 13. Overcurrent operation



For coil protection purposes, the maximum duty is further limited by the L6364 in relation to the supply voltage so that the maximum coil current rise in one cycle is limited to:

$$D_{MAX} \lesssim 19.2V / V\,(VPLUS) \Rightarrow \Delta I \lesssim 19.2V / f_{SET}\, L_{COIL}$$

For f_{SET}=1MHz, L_{COIL}=220µH, ΔI<=87mA.

16.4.3 Capacitive blocking of DOUT

C_{DOUT} provides capacitive isolation of the VPLUS supply from the DC-DC regulator. A minimum value, see Table 5. Receiver CQ/DIO, is required to correctly supply the transient currents when the DC-DC converter switches pin LOUT, and at low output currents where there is a negative current in the coil in part of the cycle. The value may, however, be increased to provide additional isolation from input voltage ripple on VPLUS.

17 Linear regulators

In addition to the DC-DC regulator, the L6364 includes two 50 mA linear regulators supplied from the V_{DCDC} pin, which have internally set output levels at V3V3 and V5V. The 3.3 V linear regulator acts as the master, and the 5.0 V linear regulator as the slave.

The start-up time of the 5.0 V linear regulator is thus dependent on the 3.3 V level, and on the size of the 3.3 V line capacitance, C_{V3V3}. The regulators' dynamic start-up behaviour under different conditions of load capacitance can be seen in Figure 14.

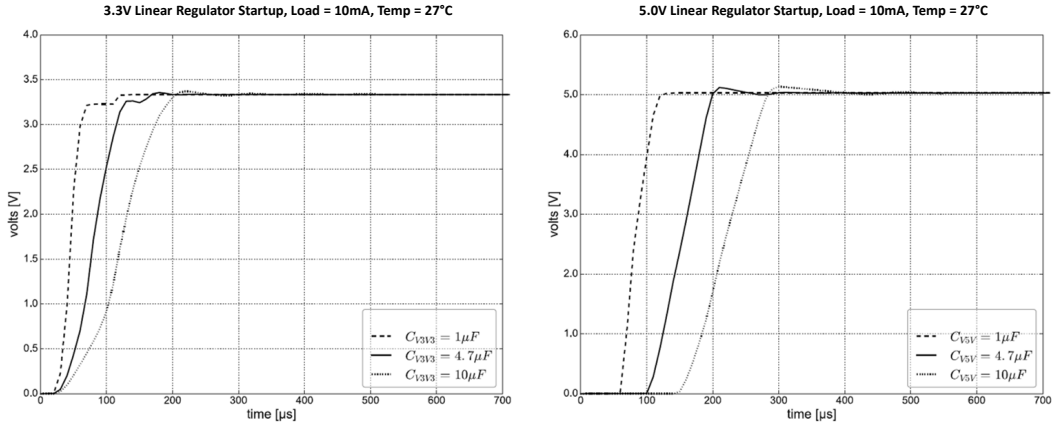
A typical load of 10mA, a supply voltage of 24 V with a rise time of 2.4 V/µs on pin V_{PLUS} were used.

The core of the L6364 device is supplied by the 3.3 V regulator, and thus an external blocking capacitor C_{V3V3} for stable operation is required and is mandatory. A maximum static load, equivalent to a resistor R_{START_MIN}, may be drawn externally on V3V3 during startup. A static load is the current which would be drawn continuously by the application circuit if the output voltage, V_{SNS}, were held at a fixed level. A load in excess of this level may block the startup.

A higher dynamic load (eg. capacitor charging) is permitted. Dynamic loads affect (slow) the start, but do not block startup.

In normal operation the consumption of the L6364 itself is limited to the quiescent current, I_{QUIES}. During startup, the static load contributed by the L6364 on the supply is limited to I_{QUIES_START}. The actual load is increased by the current drawn to charge the application capacitors and any external loads.

Figure 14. L6364 linear regulators' startup under different conditions of load capacitance



The 5.0 V regulator output is not used internally and is provided for external use. When in use, an external blocking capacitor C_{V5V} must be provided for stable operation, and the input supply range must be sufficient (V_{PLUS}>V_{SUP} in pure mode or V_{DCDC}>$V_{DCDC\_5V\_MIN}$ for DC-DC operation).

When the 5.0 V linear regulator is not in use, either permanently or periodically, then this block may be placed in a power-down state by setting bit CFG:PD5V.

When this bit is set to '1', the 5.0 V regulator is placed in power-down and the output pin, V5V, is pulled low with a discharge current of I_{PD5V}.

This ensures capacitances on the line are discharged cleanly, and that the output is tied to a known state.

18 Power dissipation

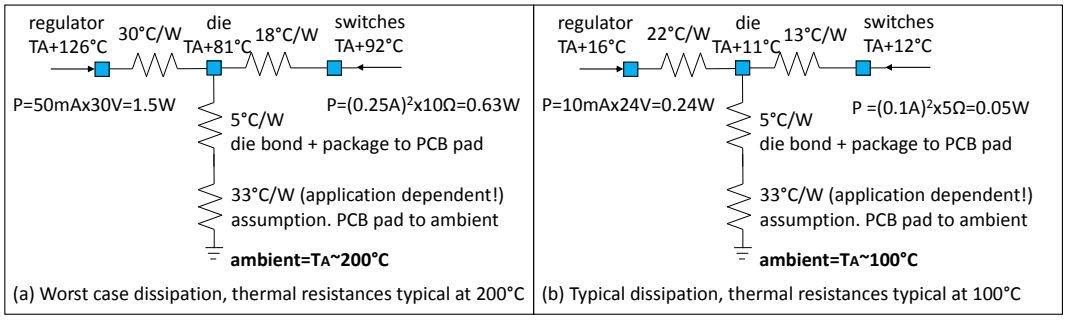
The maximum average power consumption per channel in short-circuit is:

$$max\ (I_{SAT})\ .\ max(V_{PLUS}).\ t_{SHORT}\ .\ N_{RETRY}\ /\ t_{RESTART} = 26.5mW$$

The power dissipation into an inductive load, assuming no internal losses in the inductor itself is P = Fsw ½ L I 2, where Fsw where f is the switching frequency, L the load inductance and I the operating current. The design of the application hardware should take account of this heating.

Figure 15 shows the means to estimate the device junction temperatures based on the dissipation of the regulator and switches.

Figure 15. Example of thermal power dissipation estimation

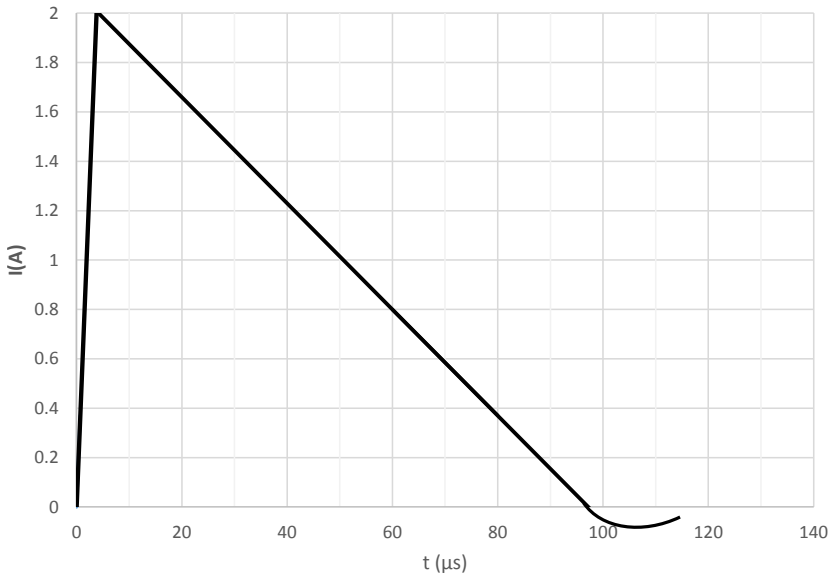


19 Surge pulse and reverse polarity protections

The PGND, CQ, DIO and VPLUS pins are fully protected by a surge protection, to withstand an asymmetric surge between any pair of these pins according to IEC 60255-5, i.e. 2A for a half-time of 50 µs.

Note that the surge stimulus is applied between the pins, rather than in common mode. This subjects the device under test to the current ratings shown in Figure 16.

Figure 16. Surge waveform



The surge protection provides a Zener like action with a protection threshold of $V_{VSURGE(CLAMP)}$, deliberately chosen to be in excess of the normal operating voltages of the L6364.

Once the surge disturbance is complete, the line voltages recover to normal levels and the Zener protection automatically ceases to conduct.

This protection style is preferred over an active snap-back protection which may continue to conduct when the operating voltages return to their nominal conditions.

Further external surge protections are compatible with the internal protections where compliance to standards exceeding the demands of IEC 60255-5 are required.

Reverse polarization protection is included in the L6364. When V3V3 is not supplied ($V(V_{PLUS}) \leq V(_{PGND})$) minimal currents, I_{REV_POL}, flow between any pair of the pins, up to a maximum voltage difference between any pair of pins of 35 V.

Note: if the L6364 is rapidly switched from a correctly polarized condition to a reverse polarized condition, such that the C_{V3V3} capacitor remains charged, then the Zener function of the CQ output causes a destructive current to flow.

Sufficient time should be allowed (ms) during testing of the reverse polarization function to allow C_{V3V3} to discharge.

20 Register Map

Figure 17. Register map

REG. NAME	ADDR	BYTE FORMAT	DESCRIPTION
MSEQ	0x00	R/W R/W R/W R/W R/W R/W R/W R/W OD1[1:0] M2CNT[3:0] OD2[1:0]	OD1[1:0] (type 1): 00 Backwards compatibility only; 01 2 octets on-demand data; 10 8 octets on-demand data; 11 Reserved OD2[1:0] (type 2): 00 1 octet on-demand data; 01 2 octets on-demand data; 10 8 octets on-demand data; 11 Reserved M2CNT[3:0] expected octet count on read
CFG	0x01	R/W R/W R/W R/W R/W R/W R R UVT[2:0] BD RF PD5V 0 0	UVT[2:0]: see Table 16 BD: 0 Baud rate 38.4kbaud; 1 Baud rate 230.4kbaud RF: 0 absolute CQ/DIO comparator ref. level; 1 CQ/DIO comparator ref. level at VPLUS/1.8 PD5V: 0 5V regulator active; 1 5V regulator inactive
CCTL	0x02	R/W R/W R/W R/W R/W R/W R/W R/W TRNS SCT[2:0] SGL SIO HS LS	TRNS: 1 set transparent mode SCT[2:0]: see Table 15 SGL: 1 Single octet UART mode SIO: 1 SIO mode requested HS: 1 enables CQ HS switch LS: 1 enables CQ LS switch
DCTL	0x03	R/W R/W R/W R/W R/W R/W R/W R/W EXT SCT[2:0] IEN DIO HS LS	EXT: 1 enable use of CTLD pin SCT[2:0]: see Table 15 IEN: 1 Level change interrupt enable DIO: 1 DIO mode requested HS: 1 enables DIO HS switch LS: 1 enables DIO LS switch
LINK	0x04	R R R/W R/W R/W R/W W W 0 0 CNT[3:0] END SND	CNT[3:0]: data bugger fill count (*) END: 1 declines sending response SND: 1 sends IO-Link response immediately
THERM	0x05	R/W R R R/W R/W R/W R/W R/W AUT 0 0 TH[4:0]	TH[4:0]: see chapter 14 Thermal shutdown AUT: 0 automatic thermal control on; 1 automatic thermal control off
TEMP	0x06	R R R R R R R R 0 TEMP[6:0]	TEMP[5:0]: see Figure 9

Figure 18. Register map (continue)

LED	0x07	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	LED1[3:0]: see chapter 15 Led outputs						
		LED1[3:0]				LED2[3:0]				LED2[3:0]: see chapter 15 Led outputs						
DCDC	0x08	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	DIS	1	Disable DC-DC converter				
		DIS	BYP	FSET[2:0]		VSET[2:0]				BYP	1	BYPASS DC-DC converter				
										FSET[2:0]: see Table 17						
										VSET[2:0]: see Table 18						
DSTAT	0x09	R	R	R	R	R	R	R	R	LVL	1	DIO Line Level				
		1	0	0	0	0	LVL	SSC	0	SSC	1	Short-Circuit triggered				
STATUS	0x0A	R/W	R	R	R	R	R	R	R	RST	0	Following reset event				
		RST	INT	UV	DINT	CHK	DAT	SSC	SOT		1	By writing this register				
										INT	1	when interrupt active prior to SPI read				
										UV	1	Under voltage triggered				
										DINT	1	DIO interrupt				
										CHK	1	Checksum or parity error				
										DAT	1	IO machine waiting to transmit				
										SSC	1	Short Circuit triggered				
										SOT	1	Over-temperature triggered				
LINK2	0xF0	R	R	R/W	R/W	R/W	R/W	W	W	CNT[3:0]:				data buffer fill count [1]		
		0	0	CNT[3:0]				END	SND	END:				Writing '1' declines sending response		
										SND:				Writing '1' sends IO-Link response after FR0 is written.		
										Note: LINK register repeated prior to frame buffer with deferred send function.						
FR0 to FR14	0x10 to 0x1E	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	2 15 octet data buffer [2]						
		DATA[7:0]														

[1] Valid CNT data may only be read when data is available (DAT bit set). If this is true, then reading the field returns the number received octets. Writing the CNT field sets the number of octets to transmit. Note that a read back will continue to read the number of octets in the received frame, and not the value written over SPI.

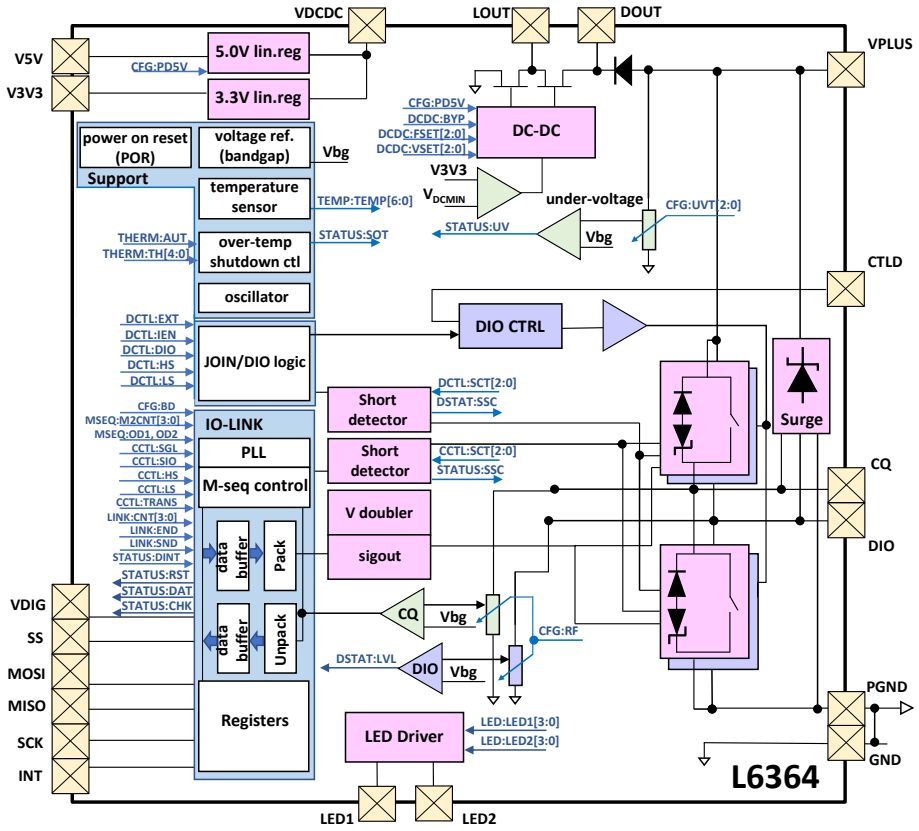
[2] The data buffer registers are only accessible when frame data is available (DAT bit set).

The initial value of all register bits following reset is '0', except bits DCDC:VSET[2:0], where the default value is 5.

21 Detailed block diagram

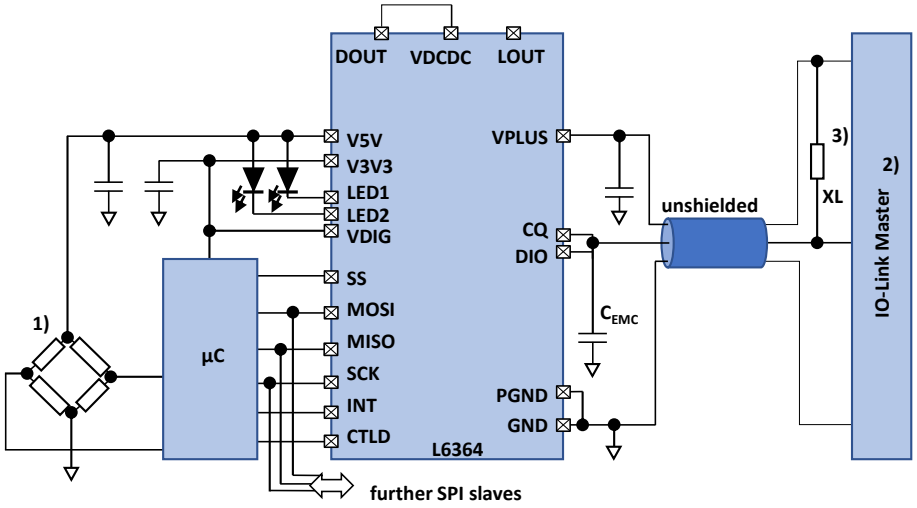
Figure 19 shows the details of the internal blocks of the L6364, and indicates which blocks the register fields act on, or are generated by.

Figure 19. Detailed block diagram, showing register field connections



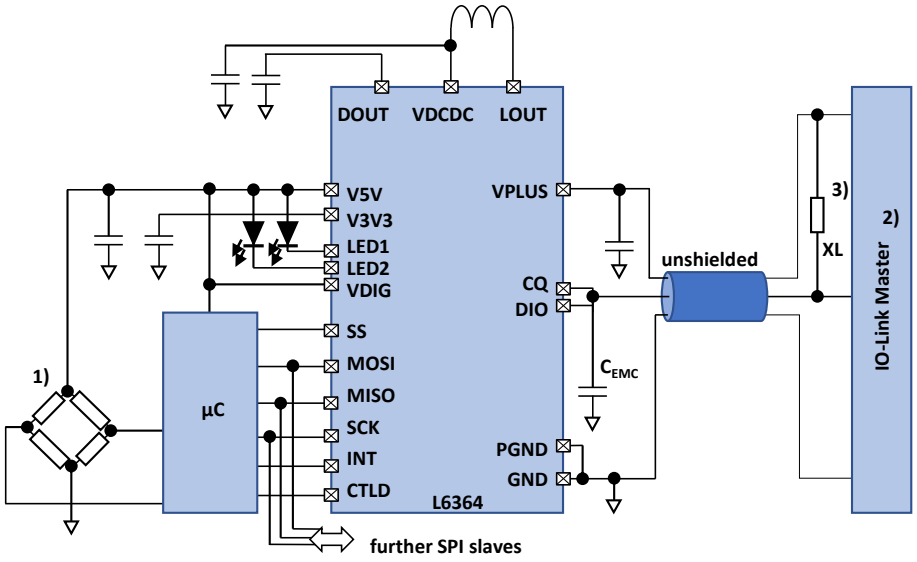
22 Typical Applications

Figure 20. Application example: DCDC disabled, CQ and DIO coupled (Join Mode), V_{SENSOR} = 5 V, V_{MCU} = VDIG = 3.3 V



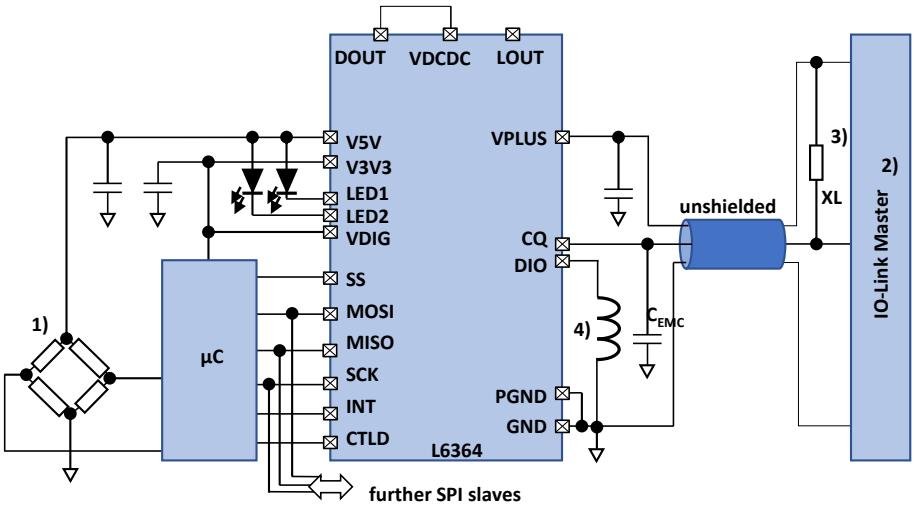
1) AFE (sensor)
2) IO-Link master is used for IO-Link mode and device configuration
3) XL (high or low-side) in Single Input Output mode

Figure 21. Application example: DCDC enabled, CQ and DIO coupled (Join Mode), V_{SENSOR} = V_{MCU} = VDIG = 5.0 V



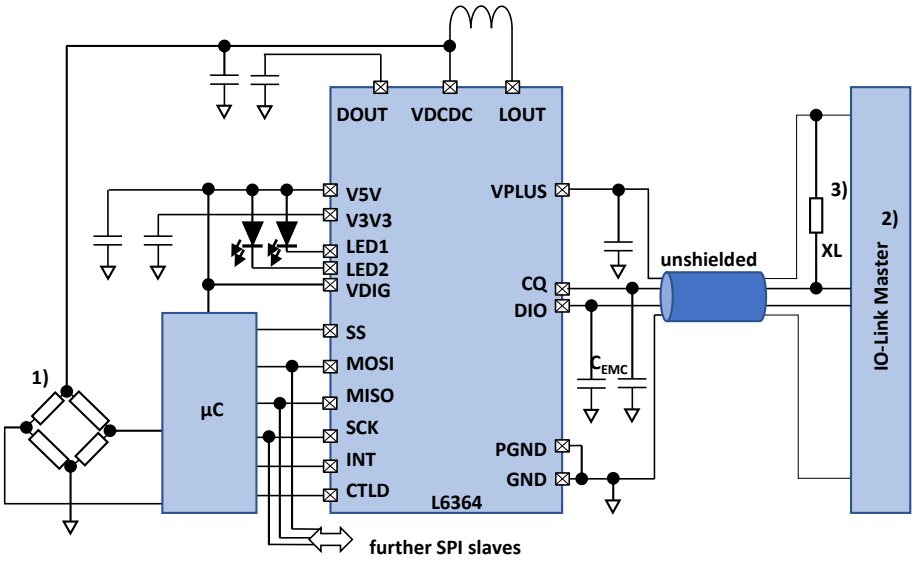
1) AFE (sensor)
2) IO-Link master is used for IO-Link mode and device configuration
3) XL (high or low-side) in Single Input Output mode

Figure 22. **Application example: DCDC disabled, CQ as line driver, DIO as load driver, V_{SENSOR} = 5.0 V, V_{MCU} = VDIG = 3.3 V**



1) AFE (sensor)
2) IO-Link master is used for IO-Link mode and device configuration
3) XL (high or low-side) in Single Input Output mode
4) Industrial Load (e.g. Valve)

Figure 23. **Application example: DCDC enabled, CQ and DIO as independent line drivers, V_{SENSOR} > 5.0 V, V_{MCU} = VDIG = 5.0 V**



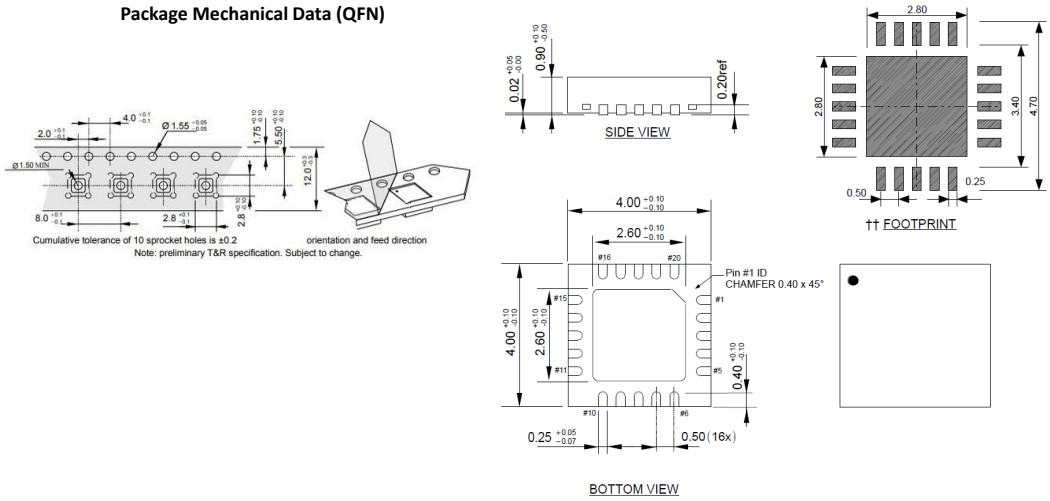
1) AFE (sensor)
2) IO-Link master is used for IO-Link mode and device configuration
3) XL (high or low-side) in Single Input Output mode
4) Industrial Load (e.g. Valve)

23 Package Mechanical Data

In order to meet environmental requirements, ST offers these devices in ECOPACK® packages. These packages have a Lead-free second level interconnect. The category of second level interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label. ECOPACK is an ST trademark.

ECOPACK specifications are available at: www.st.com

Figure 24. Package, footprint and tape drawings for QFN



Revision history

Table 32. **Document revision history**

Date	Version	Changes
11-Aug-2020	1	Initial release.
21-Oct-2020	2	Replaced Figure 1, Figure 2, Figure 17, Figure 18, Figure 19, Figure 20 and Figure 21 added Figure 22 and Figure 23.

Contents

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List of figures