IQS7221E DATASHEET

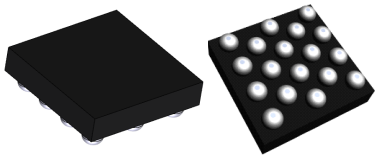
ProxFusion® device for on-axis Hall-effect angle measurements, including quadrature output, an additional ProxFusion® touch channel, and an on-chip freewheel UI

1 Device Overview

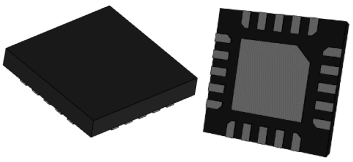
The IQS7221E ProxFusion® IC is a sensor fusion device for rotation and angle sensing applications designed for on-axis orientation. A ProxFusion® channel is included for integrated UI applications. Two dedicated quadrature outputs make the product a drop-in replacement for mechanical and optical rotary encoders. The IQS7221E includes a virtual freewheel UI for more intuitive scrolling.

1.1 Main Features

- Highly flexible ProxFusion® device
- Hall effect angle sensor
  - 4 Hall plates
  - Supports on-axis orientation
  - 16-bit absolute angle output
  - < 1° resolution, calculated on-chip
  - Relative/Absolute rotation angle
  - Detect movement and the direction of movement
  - Wide operational range
  - Automatic Tuning Implementation (ATI)
  - Automatic synchronisation with mechanical ratchets
- ProxFusion® Channel
  - Supports one self-capacitive or mutual-capacitive sensor
  - Ultra-low power wake-up on touch
  - Full auto-tuning (ATI) with adjustable sensitivity
- Sensor flexibility
  - Internal voltage regulator
  - No external components required for Hall measurements
  - I^2C Interface with IRQ line
- Design simplicity and support
  - PC software for debugging and configuring for optimal performance
  - Magnet and mechanical constraints, guidelines and best practices
- Multiple integrated UIs
  - Proximity and touch events on ProxFusion® channel
  - Proximity wake-up from ultra-low power mode
  - Hysteresis interval mode
  - Event modes with configurable angle-change, interval or touch / prox events
  - Quadrature standalone output for Hall measurements
  - Virtual freewheel UI
- Supply Voltage 2 V to 3.5 V
- Small packages
  - WLCSP18 (1.62 × 1.62 × 0.5 mm) – interleaved 0.4 mm × 0.6 mm ball pitch
  - QFN20 (3 × 3 × 0.5 mm) – 0.4 mm pitch



WLCSP18 & QFN20 package
Representation only



1.2 Applications

- Scroll-wheels for computer peripherals
- Mouse wheels
- Applications requiring flexible UI options with Sensor Fusion
- Mechanical and optical rotary encoder replacements
- Adjustment and control knobs
- Motor encoders

1.3 Block Diagram

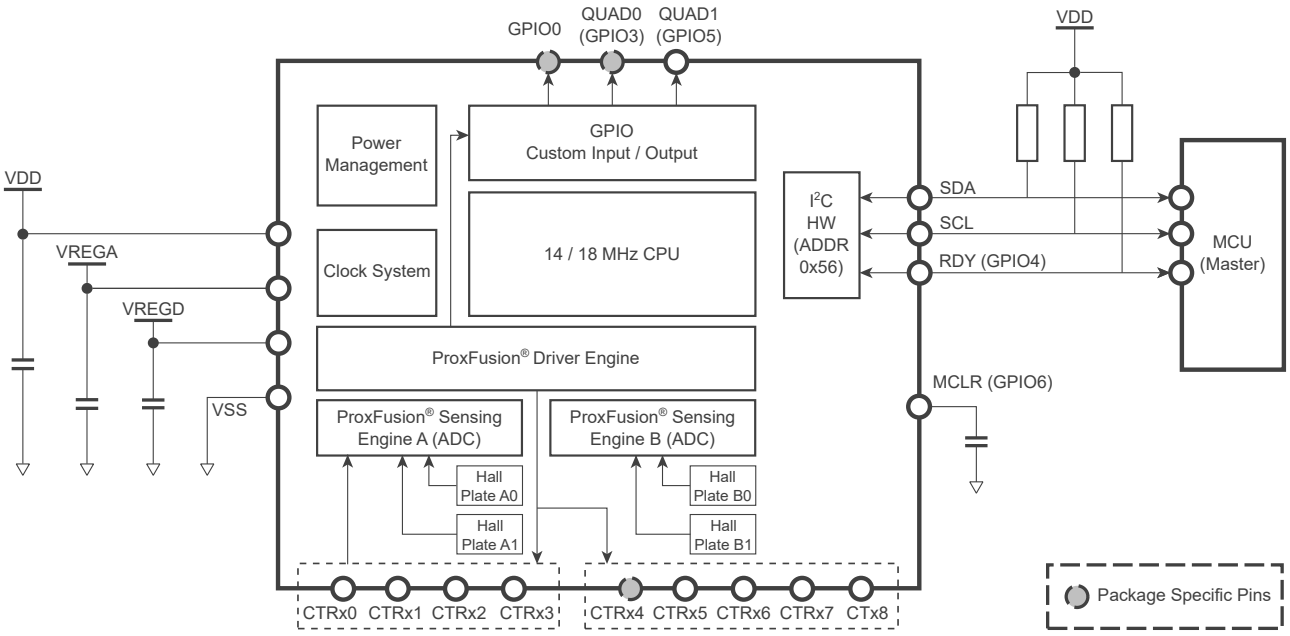


Figure 1.1: Functional Block Diagram[i]

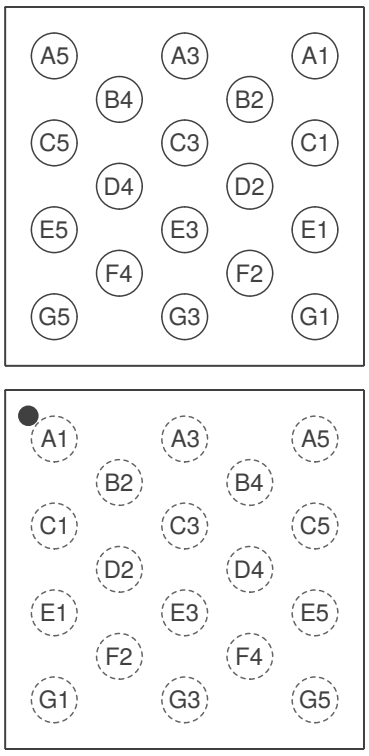
[i] WLCSP18 packages do not have a CRx4 and combines GPIO0 and GPIO3.

Contents

2 Hardware Connection

2.1 WLCSP18 Pin Diagrams

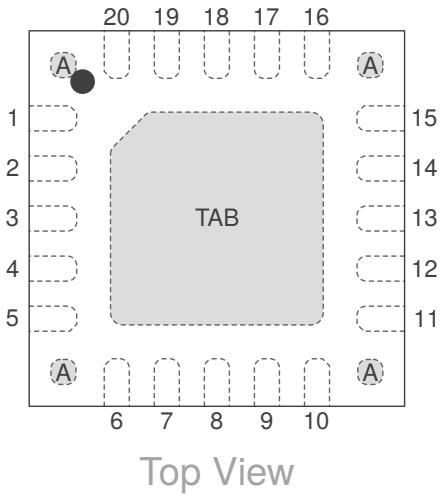
Table 2.1: 18-pin WLCSP18 Package



Pin no.	Signal
A1	QUAD0
A3	SCL
A5	MCLR
B2	RDY
B4	SDA
C1	CTx8
C3	QUAD1
C5	VDD
D2	CRx2/CTx2
D4	VSS
E1	CRx6/CTx6
E3	CRx1/CTx1
E5	VREGD
F2	CRx5/CTx5
F4	CRx0/CTx0
G1	CRx7/CTx7
G3	CRx3/CTx3
G5	VREGA

2.2 QFN20 Pin Diagram

Table 2.2: 20-pin QFN Package (Top View)



Pin no.	Signal name	Pin no.	Signal name
1	VDD	11	CRx6/CTx6
2	VREGD	12	CRx7/CTx7
3	VSS	13	CTx8
4	VREGA	14	NC
5	CRx0/CTx0	15	QUAD0
6	CRx1/CTx1	16	RDY
7	CRx2/CTx2	17	QUAD1
8	CRx3/CTx3	18	SCL
9	CRx4/CTx4	19	SDA
10	CRx5/CTx5	20	MCLR

Area name	Signal name
TAB[i]	Thermal pad (floating)
A[ii]	Thermal pad (floating)

[i] It is recommended to connect the thermal pad (TAB) to VSS.
[ii] Electrically connected to TAB. These exposed pads are only present on *–QNR* order codes.

2.3 Pin Attributes

Table 2.3: Pin Attributes

Pin no.		Signal name	Signal type	Buffer type	Power source
WLCSP18	QFN20				
C5	1	VDD	Power	Power	N/A
E5	2	VREGD	Power	Power	N/A
D4	3	VSS	Power	Power	N/A
G5	4	VREGA	Power	Power	N/A
F4	5	CRx0/CTx0	Analog		VREGA
E3	6	CRx1/CTx1	Analog		VREGA
D2	7	CRx2/CTx2	Analog		VREGA
G3	8	CRx3/CTx3	Analog		VREGA
-	9	CRx4/CTx4	Analog		VREGA
F2	10	CRx5/CTx5	Analog		VREGA
E1	11	CRx6/CTx6	Analog		VREGA
G1	12	CRx7/CTx7	Analog		VREGA
C1	13	CTx8	Analog		VREGA
-	14	NC	Digital		VDD
B4	19	SDA	Digital		VDD
A3	18	SCL	Digital		VDD
A1	15	QUAD0	Digital		VDD
B2	16	RDY	Digital		VDD
C3	17	QUAD1	Digital		VDD
A5	20	MCLR	Digital		VDD

2.4 Signal Descriptions

Table 2.4: Signal Descriptions

Function	Signal name	Pin no.		Pin type[iii]	Description
		WLCSP18	QFN20		
ProxFusion®	CRx0/CTx0	F4	5	IO	ProxFusion® channel
	CRx1/CTx1	E3	6	IO	
	CRx2/CTx2	D2	7	IO	
	CRx3/CTx3	G3	8	IO	
	CRx4/CTx4	-	9	IO	
	CRx5/CTx5	F2	10	IO	
	CRx6/CTx6	E1	11	IO	
	CRx7/CTx7	G1	12	IO	
	CTx8	C1	13	O	CTx8 pad
GPIO	NC	-	14	-	Not connected
	QUAD0	A1	15	O	Quadrature output pin 0
	RDY	B2	16	O	RDY pad
	QUAD1	C3	17	O	Quadrature output pin 1
	MCLR	A5	20	IO	Active pull-up, 200k resistor to VDD. Pulled low during POR, and MCLR function enabled by default. VPP input for OTP.
I^2C	SDA	B4	19	IO	I^2C data
	SCL	A3	18	IO	I^2C clock
Power	VDD	C5	1	P	Power supply input voltage
	VREGD	E5	2	P	Internal regulated supply output for digital domain
	VSS	D4	3	P	Analog/digital ground
	VREGA	G5	4	P	Internal regulated supply output for analog domain

[iii] Pin Types: I = Input, O = Output, IO = Input or Output, P = Power.

2.5 Reference Schematic

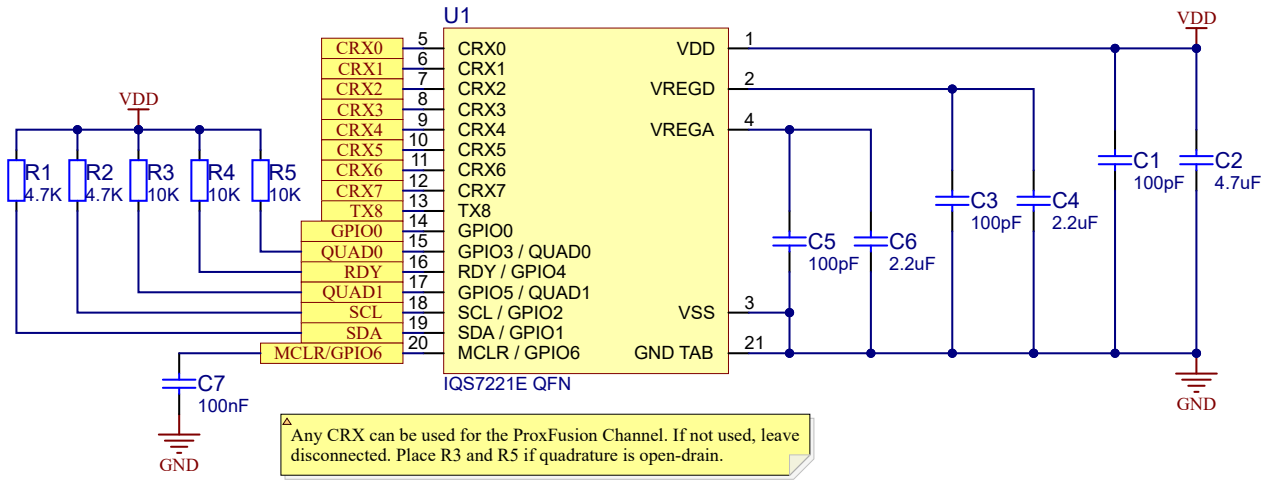


Figure 2.1: IQS7221E QFN Reference Schematic

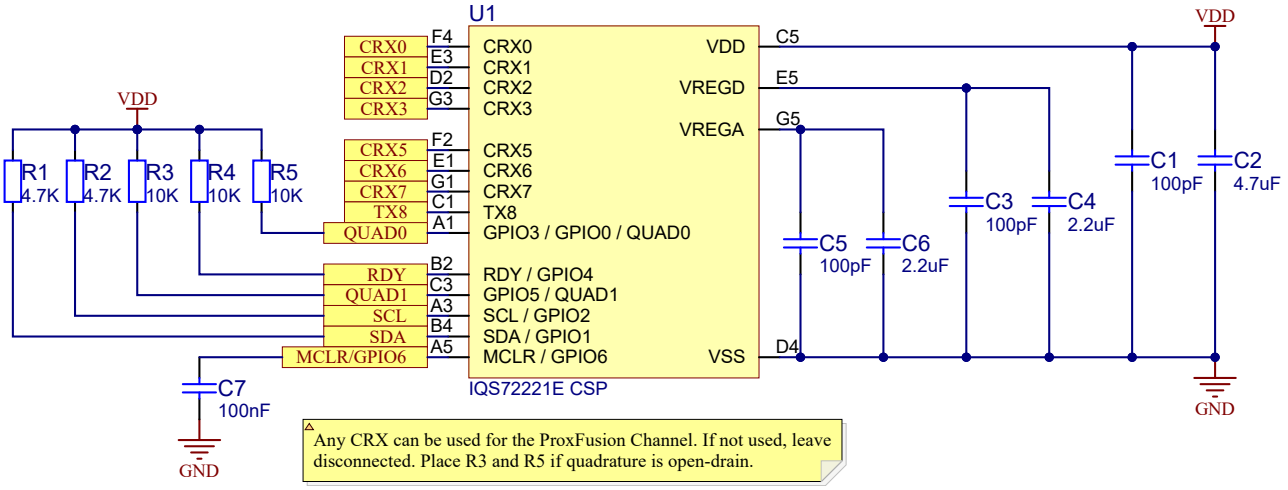


Figure 2.2: IQS7221E CSP Reference Schematic

2.6 Hall Plate Positions

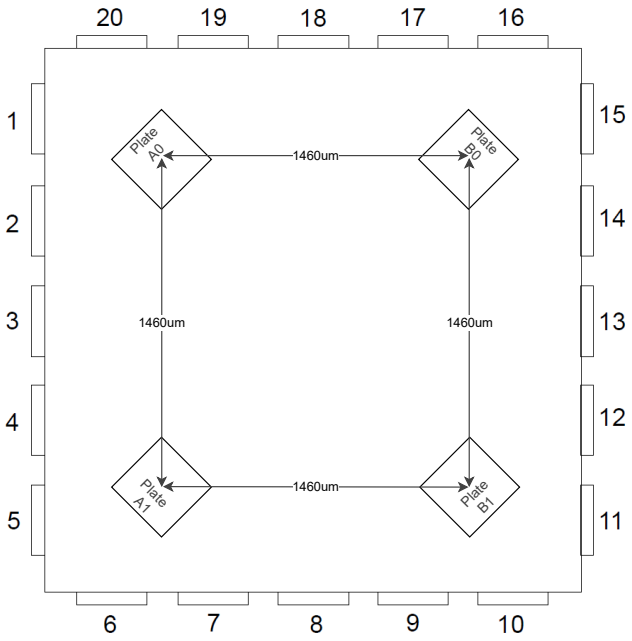


Figure 2.3: Plate Layout QFN (Top View)

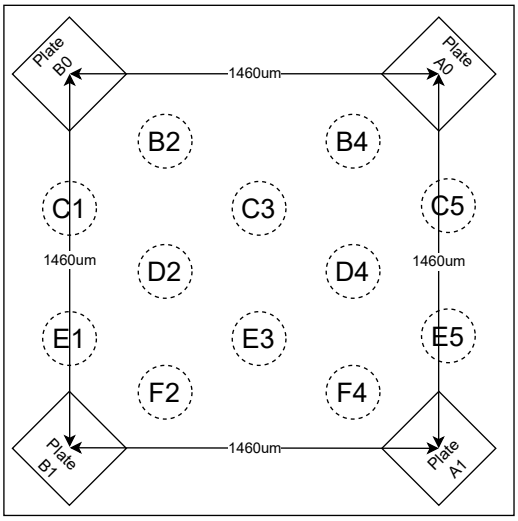


Figure 2.4: Plate Layout WLCSP (Top View)

3 Electrical Characteristics

3.1 Absolute Maximum Ratings

Table 3.1: Absolute Maximum Ratings

	Min	Max	Unit
Voltage applied at VDD pin to VSS	2[i]	3.5	V
Voltage applied to any ProxFusion® pin (referenced to VSS)	–0.3	VREGA	V
Voltage applied to any other pin (referenced to VSS)	–0.3	VDD + 0.3 (3.5 V max)	V
Storage temperature, T_{stg}	–40	85	°C

3.2 Recommended Operating Conditions

Table 3.2: Recommended Operating Conditions

		Min	Nom	Max	Unit
VDD	Supply voltage applied at VDD pin: F_{OSC} = 14 MHz F_{OSC} = 18 MHz	 2 2.2		 3.5 3.5	V
VREGA	Internal regulated supply output for analog domain: F_{OSC} = 14 MHz F_{OSC} = 18 MHz	 1.49 1.7	 1.53 1.75	 1.57 1.79	V
VREGD	Internal regulated supply output for digital domain: F_{OSC} = 14 MHz F_{OSC} = 18 MHz	 1.56 1.75	 1.59 1.8	 1.64 1.85	V
VSS	Supply voltage applied at VSS pin		0		V
T_A	Operating free-air temperature	–40	25	85	°C
C_{VDD}	Recommended capacitor at VDD	$2\times C_{VREGA}$	$3\times C_{VREGA}$		µF
C_{VREGA}	Recommended external buffer capacitor at VREGA, ESR≤ 200 mΩ	2	4.7	10	µF
C_{VREGD}	Recommended external buffer capacitor at VREGD, ESR≤ 200 mΩ	2	4.7	10	µF
$Cx_{SELF–VSS}$	Maximum capacitance between ground and all external electrodes on all ProxFusion® blocks (self-capacitance mode)	1		400[ii]	pF
$Cm_{CTx–CRx}$	Capacitance between Receiving and Transmitting electrodes on all ProxFusion® blocks (mutual-capacitance mode)	0.2		9[ii]	pF
$Cp_{CRx–VSS}$	Maximum capacitance between ground and all external electrodes on all ProxFusion® blocks Mutual-capacitance mode, f_{xfer} = 1 MHz Mutual-capacitance mode, f_{xfer} = 4 MHz			 100[ii] 25[ii]	pF
$\frac{Cp_{CRx–VSS}}{Cm_{CTx–CRx}}$	Capacitance ratio for optimal SNR in mutual-capacitance mode[iii]	10		20	n/a
$RCx_{CRx/CTx}$	Series (in-line) resistance of all mutual-capacitance pins (Tx & Rx pins) in mutual-capacitance mode	0[iv]	0.47	10[v]	kΩ
RCx_{SELF}	Series (in-line) resistance of all self-capacitance pins in self-capacitance mode	0[iv]	0.47	10[v]	kΩ

3.3 ESD Rating

Table 3.3: ESD Rating

		Value	Unit
$V_{(ESD)}$ Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[vi]	±4000	V

3.4 Order Code Variants

Currently, three distinct order codes for the IQS7221E are available:

- **IQS7221E001***ppb* supports only 18 MHz F_{OSC}. A minimum VDD voltage of 2.2 V[i] is required for reliable operation.
- **IQS7221E002***ppb* is identical to IQS7221E001*ppb*, with an alternative I^2C address.
- **IQS7221E101***ppb* offers reduced current consumption, as well as the option to select either 14 MHz or 18 MHz F_{OSC} during runtime via the **F_{OSC} Selection** bit. Running the IQS7221E at 14 MHz lowers the minimum required VDD voltage to 2 V.

Please see Section 12 for more information regarding the IQS7221E order codes.

3.5 Current Consumption

The following tables record the typical current consumption of the IQS7221E in different power modes, with a supply voltage of 3.3 V. These values assume mostly default settings, but with I^2C disabled (i.e. “standalone mode” or “event mode”).

The current consumption values for the following three setups are shown:

- Hall & Touch: Both the Hall channels and touch channels are sampled, and all related UIs are enabled.
- Hall Only: The Hall channels and UIs are enabled. The touch channel is disabled by clearing the **Button Enable** bit.
- Touch Only: Only the touch channel is enabled. Hall-rotation sensing is disabled by clearing both the **Hall UI Enable** bit and the **Hall Sensor Enable** bit.

[i] When running at 18 MHz, a 2.2 V supply is recommended. With a 2 V supply, at least 20 mT peak Z-axis field strength at the Hall plate is recommended in order to combat the decreased power supply rejection ratio. The use of the self-capacitance channel is not recommended as it is particularly susceptible to increased supply noise.

[ii] RCx = 0 Ω.

[iii] Please note that the maximum values for Cp and Cm are subject to this ratio.

[iv] Nominal series resistance of 470 Ω is recommended to prevent received and emitted EMI effects. Typical resistance also adds additional ESD protection.

[v] Series resistance limit is a function of F_{xfer} and the circuit time constant, RC. $R_{max} \times C_{max} = \frac{1}{(6 \times f_{xfer})}$ where C is the pin capacitance to VSS.

[vi] JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Pins listed as ±4000 V may actually have higher performance.

3.5.1 IQS7221E101 at 18 MHz

Table 3.4: IQS7221E Typical Current Consumption for IQS7221E101 at 3.3 V VDD and 18 MHz F_{OSC}

Power Mode	Report Rate [ms]	Current Consumption [µA]		
		Hall & Touch	Hall	Touch
High-accuracy	5	650	635	300
Normal power	40	120	100	55
Low power	200	30	25	15
Ultra low power[vii]	500	N/A	N/A	9

3.5.2 IQS7221E101 at 14 MHz

Table 3.5: IQS7221E Typical Current Consumption for IQS7221E101 at 3.3 V VDD and 14 MHz F_{OSC}

Power Mode	Report Rate [ms]	Current Consumption [µA]		
		Hall & Touch	Hall	Touch
High-accuracy	5	690	590	245
Normal power	40	115	100	55
Low power	200	25	23	13
Ultra low power[vii]	500	N/A	N/A	7

3.5.3 IQS7221E001/002 at 18 MHz

Table 3.6: IQS7221E Typical Current Consumption at 3.3 V VDD, 18 MHz

Power Mode	Report Rate [ms]	Current Consumption [µA]		
		Hall & Touch	Hall	Touch
High-accuracy	5	1340	1015	640
Normal power	40	205	165	105
Low power	200	45	40	30
Ultra low power[vii]	500	N/A	N/A	10

[vii] Only the touch channel is sampled during ULP.

4 Timing and Switching Characteristics

4.1 Reset Levels

Table 4.1: Reset Levels

Parameter		Min	Typ	Max	Unit
V_{VDD}	Power-up/down level (Reset trigger) – slope > 100 V/s	1.040	1.353	1.568	V
V_{VREGD}	Power-up/down level (Reset trigger) – slope > 100 V/s	0.945	1.122	1.304	V

4.2 MCLR Pin Levels and Characteristics

Table 4.2: MCLR Pin Characteristics

Parameter		Conditions	Min	Typ	Max	Unit
$V_{IL(MCLR)}$	MCLR Input low level voltage	VDD = 3.3 V	VSS – 0.3	-	1.05	V
		VDD = 1.7 V			0.75	
$V_{IH(MCLR)}$	MCLR Input high level voltage	VDD = 3.3 V	2.25	-	VDD + 0.3	V
		VDD = 1.7 V	1.05			
$R_{PU(MCLR)}$	MCLR pull-up equivalent resistor		180	210	240	kΩ
$t_{PULSE(MCLR)}$	MCLR input pulse width – no trigger	VDD = 3.3 V	-	-	15	ns
		VDD = 1.7 V			10	
$t_{TRIG(MCLR)}$	MCLR input pulse width – ensure trigger		250	-	-	ns

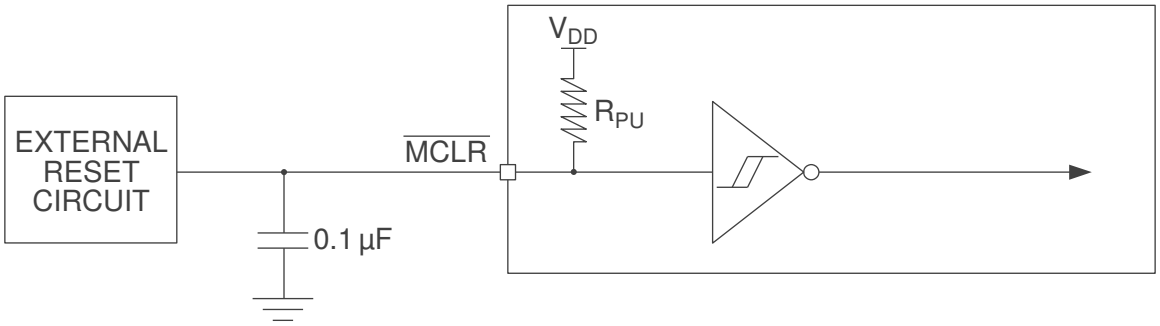


Figure 4.1: MCLR Pin Diagram

4.3 Miscellaneous Timings

Table 4.3: Miscellaneous Timings

Parameter		Min	Typ	Max	Unit
F_{OSC}	Master CLK frequency tolerance 14 MHz	13.23	14	14.77	MHz
F_{OSC}	Master CLK frequency tolerance 18 MHz	17.1	18	19.54	MHz
F_{xfer}	Charge transfer frequency (derived from F_{OSC})	42	500 – 1500	4500	kHz

4.4 Digital I/O Characteristics

Table 4.4: Digital I/O Characteristics

Parameter		Test Conditions	Min	Typ	Max	Unit
V_{OL}	SDA & SCL Output low voltage	I_{sink} = 20 mA			0.3	V
V_{OL}	GPIO[i] Output low voltage	I_{sink} = 10 mA			0.15	V
V_{OH}	Output high voltage	I_{source} = 20 mA	VDD – 0.2			V
V_{IL}	Input low voltage				VDD × 0.3	V
V_{IH}	Input high voltage		VDD × 0.7			V
C_{b_max}	SDA & SCL maximum bus capacitance				550	pF

4.5 I²C Characteristics

Table 4.5: I²C Characteristics

Parameter		VDD	Min	Typ	Max	Unit
f_{SCL}	SCL clock frequency	1.8 V, 3.3 V			1000	kHz
$t_{HD,STA}$	Hold time (repeated) START	1.8 V, 3.3 V	0.26			µs
$t_{SU,STA}$	Setup time for a repeated START	1.8 V, 3.3 V	0.26			µs
$t_{HD,DAT}$	Data hold time	1.8 V, 3.3 V	0			ns
$t_{SU,DAT}$	Data setup time	1.8 V, 3.3 V	50			ns
$t_{SU,STO}$	Setup time for STOP	1.8 V, 3.3 V	0.26			µs
t_{SP}	Pulse duration of spikes suppressed by input filter	1.8 V, 3.3 V	0		50	ns

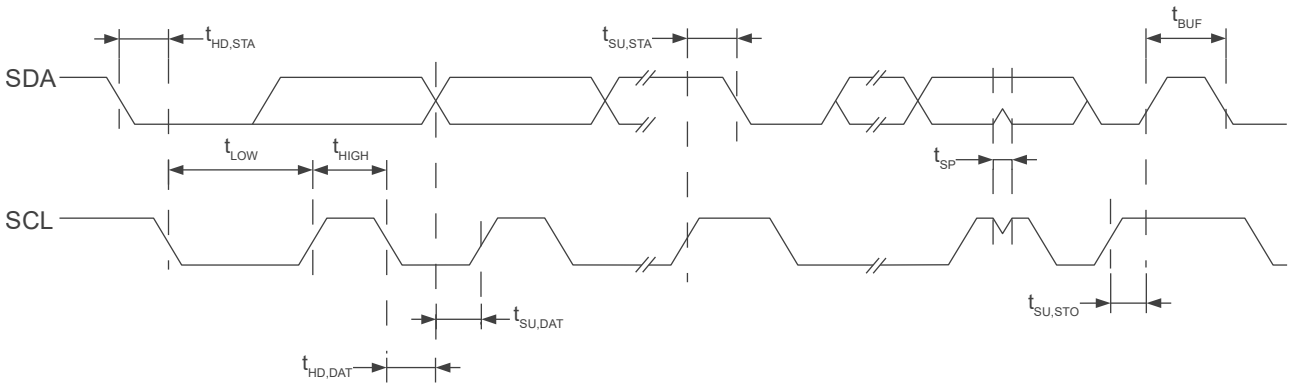


Figure 4.2: I²C Mode Timing Diagram

[i] Refers to NC, QUAD0, RDY, and QUAD1 pins.

5 ProxFusion® Hall Sensor Module

The IQS7221E contains four equally-spaced Hall plates that measure the magnetic field strength and orientation of a nearby diametrically-polarised magnet. Two ProxFusion® modules allow for simultaneous sampling of two Hall plates at a time, improving the responsiveness of the system. The Hall sensor provides an interval UI to track the current angle of the magnet. The I^2C interface can be used to track the absolute angle of the magnet. The quadrature outputs provide an interface for relative angle tracking in low-power systems and can act as a drop-in replacement for existing digital rotational encoders.

5.1 Magnet Orientation

The IQS7221E is designed to be used in an on-axis orientation with regard to the magnet, as shown in Figure 5.1.

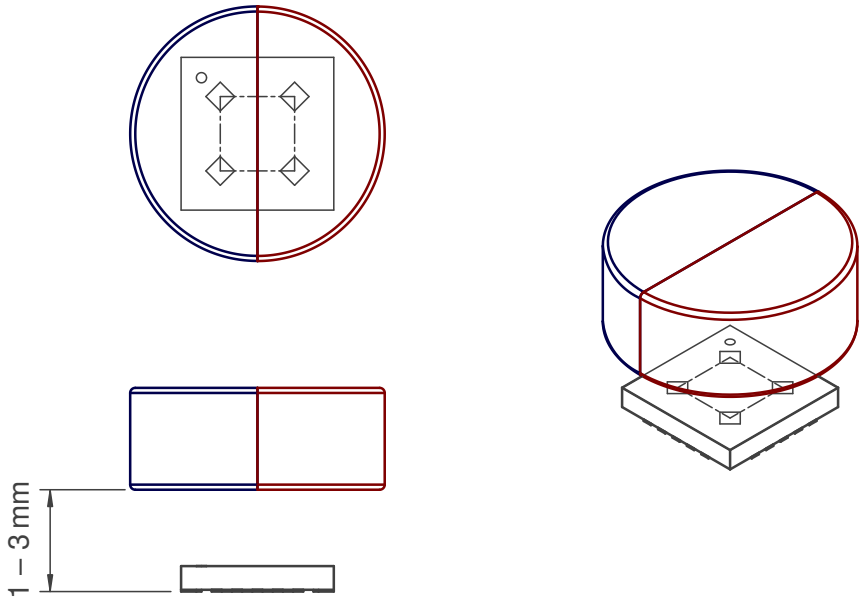


Figure 5.1: Magnet Orientation of an On-axis Angle Measurement Application

Please refer to AZD127 for more information regarding on-axis design guidelines.

5.2 Hall Rotation Measurements

The IQS7221E provides the angle measurement as three different values:

- **Absolute Angle**: Raw angle measurement, provided as an unsigned 16-bit value, where the range [0, 65536) maps to [0°, 360°). This represents the angle of the magnet relative to the IC.
- **Processed Angle**: Angle measurement after post-processing, also an unsigned 16-bit value. This output is filtered and includes an angular offset. This output is recommended for applications requiring high-resolution measurements.
- **Interval**: The output of the interval UI, which divides the unsigned 16-bit processed angle into several sections, or intervals. This output is recommended for applications with mechanical ratchets and is supplemented by the hysteresis, auto-zero, and quadrature features.

5.3 Hall Rotation Channels

The Hall effect measurement on the IQS7221E relies on two measurements on each of the four Hall plates, where the second measurement is inverted to the first. These two measurements allow for the calculation of a reference value from which the relative strength of the magnetic field can be inferred. This reference value is calculated as

$$\text{Hall Reference} = \frac{2}{\frac{1}{\text{Counts}} + \frac{1}{\text{Inverted Counts}}}. \tag{1}$$

As a result, the IQS7221E has eight Hall effect channels, four of which are inverted to the others. The channel samples are available in the **Hall plate counts** and **Hall reference** registers.

5.4 Automatic Tuning Implementation (ATI)

ATI is an automatic sensor calibration algorithm which will configure the **Hall plate settings** to allow for accurate Hall effect sensing on a range of different magnet sizes and strengths. The ATI aims to modify the Hall plate settings such that the Hall channel reference values are within the range defined by the **target minimum** and **target maximum** parameters. The resulting Hall reference will be approximately equal to a target reference value defined as

$$\text{Target Reference} = \frac{2}{\frac{1}{\text{Target Max}} + \frac{1}{\text{Target Min}}}. \tag{2}$$

5.5 Runtime ATI

ATI is performed at start-up as well as when all the following criteria are met:

- The stationary flag is set, see Section 5.9.
- The **Hall reference** of a channel is outside the threshold defined by Equation (3).

$$|\text{Target Reference} - \text{Hall Reference}| > \frac{\text{Target Max} - \text{Target Min}}{\text{Hall ATI Band Fraction}} \tag{3}$$

- Runtime ATI is enabled in **Hall UI settings**.

5.6 Filtering

High-frequency variations in the angle are filtered out according to the parameters defined under **Hall filter settings**. The IC features a slow filter and a fast filter. The slow filter is active by default. The fast filter is activated when the difference between the outputs of the fast and slow filters exceeds the **filter switch threshold**. This ensures low jitter on the output angle during slow rotations as well as responsiveness to fast rotations.

5.7 Interval UI

The interval UI divides the 16-bit processed angle into a value between 0 and **number of intervals**, where the size of each interval is defined as

$$\text{Interval Size} = \frac{2^{16}}{\text{Number of Intervals}}. \tag{4}$$

This is especially useful for applications that do not require a high measurement resolution, or that use mechanical ratchets.

The interval UI is also used for the quadrature UI. On interval change, the IQS7221E will output a quadrature event on the quadrature pins. The device can also open an I²C communications window on interval change if **I²C streaming** is enabled.

*It is recommended to send a **Zero-Now** command after changing the number of intervals.*

5.7.1 Interval Hysteresis

The interval hysteresis prevents the interval output from jittering between two intervals, causing unnecessary interval-change events. The behaviour of the hysteresis is shown in Figure 5.2.

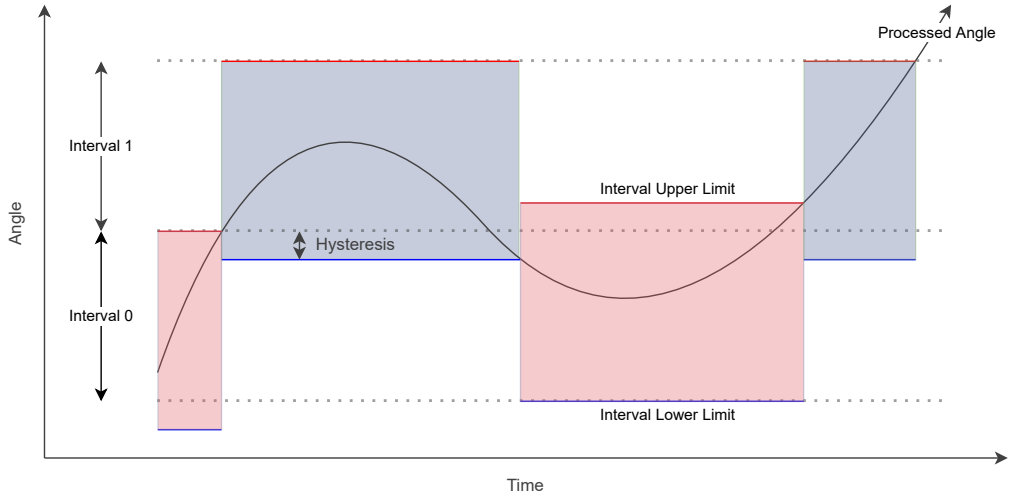


Figure 5.2: Illustration of the Interval Size and Interval Hysteresis

The amount of hysteresis applied can be modified by changing the **interval hysteresis** value.

5.8 High-accuracy Mode

The high-accuracy mode of the IQS7221E will increase the report rate of the device to sample Hall rotation measurements more accurately, and to reduce aliasing during high rotation rates.

The IQS7221E will enter high-accuracy mode in the event of:

- An interval change
- Freewheeling when the “force high-accuracy” bit is set under the **Hall UI settings** register.
- The difference between fast and slow filtered values exceeds the **filter switch threshold**.

The **high-accuracy** flag will remain set for the duration of the **high-accuracy timeout**. This flag is used to identify whether to go into high-accuracy mode, and can be configured to signal an automatic interval centering event when high-accuracy mode is exited.

5.9 Stationary Detection

The IQS7221E will set a stationary flag if no movement is detected during the period defined by the **stationary timeout** value. This stationary flag is used to identify whether to go into a lower power mode, and can be configured to signal an automatic interval centering event. Runtime ATI for the Hall channels is also only executed when stationary.

5.10 Angle Offset Compensation

Angle offset compensation is applied to ensure the output angle corresponds to the angle of the wheel and not the angle of the magnet. This is especially important for ratchet applications where intervals output by the IC are required to correspond to the mechanically-defined intervals of the wheel.

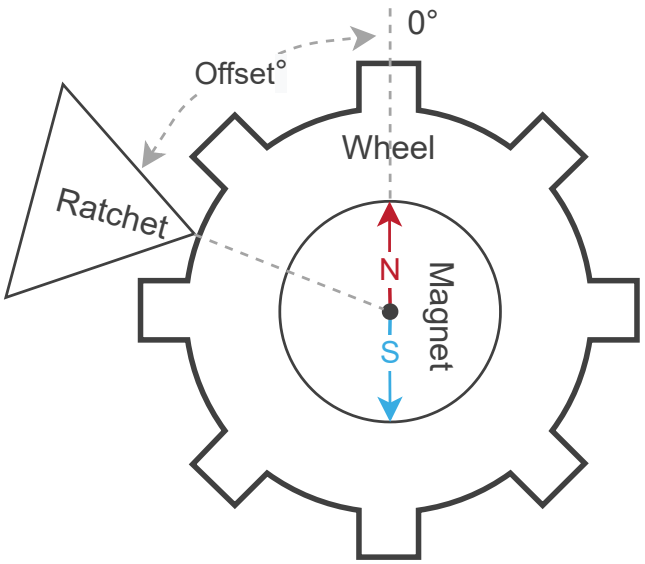


Figure 5.3: Illustration of the Absolute Angle Offset

Three forms of offset compensation can be applied:

- Manual Offset Compensation
- Start-up Offset Compensation
- Automatic Offset Compensation

5.11 Interval Centering

The interval centering functionality of the IQS7221E allows the device to modify the absolute angle offset of the final angle such that the final angle is at the center of the current interval. This is very useful for configuring the absolute angle offset to align with the physical intervals of a ratchet device.

The device can be configured to automatically trigger an interval centering action. Alternatively, the *zero now* bit can be set in the **Hall UI settings** to set the absolute angle offset such that the **processed angle** is at the center of the first interval.

The auto-zero mode can be set in the **Hall UI settings** to four different settings:

- **Off**: The device will never allow an automatic interval zero action to happen, and the master device will have to send an instruction over I^2C to set the *zero now* bit.

- **Stationary**: An auto-zero event will occur when the high-accuracy timeout event occurs. A single adjustment is made to the absolute angle offset each time the device exits high-accuracy mode. The **auto-zero beta** parameter defines the size of the adjustment, with an auto-zero beta value of 0 resulting in a jump to the exact center of the interval. This behaviour can be viewed in Figure 5.4.
- **Continuous**: The auto-zero filter will always be active and will cause the final angle to continuously move towards the center of the current interval. It is recommended to use a high **auto-zero beta** value to allow the final angle to move between intervals during slower rotations. This mode applies to devices without a mechanical ratchet, or with haptic ratchet effects. This behaviour can be viewed in Figure 5.5
- **Release**: An auto-zero event will occur when the touch release event occurs in addition to the criterion for the stationary auto-zero mode.

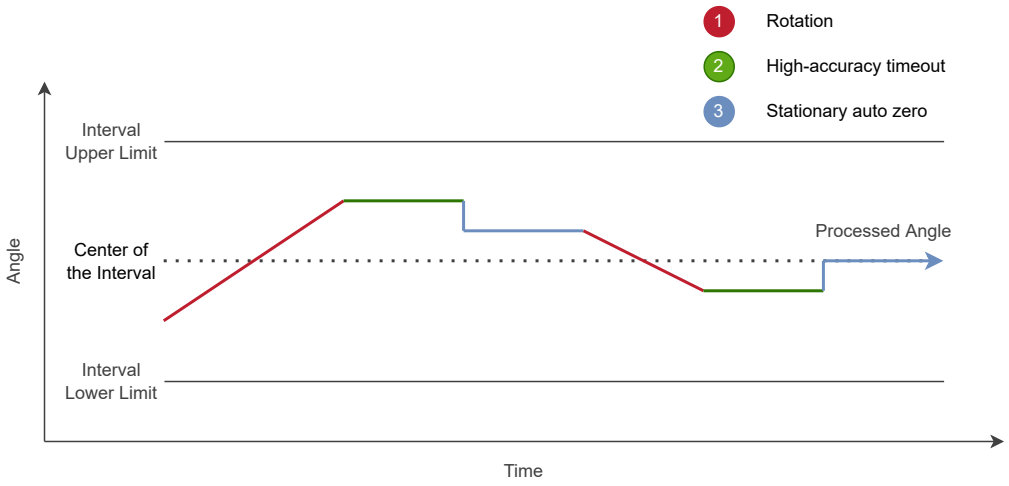


Figure 5.4: Stationary Auto-zero Behaviour

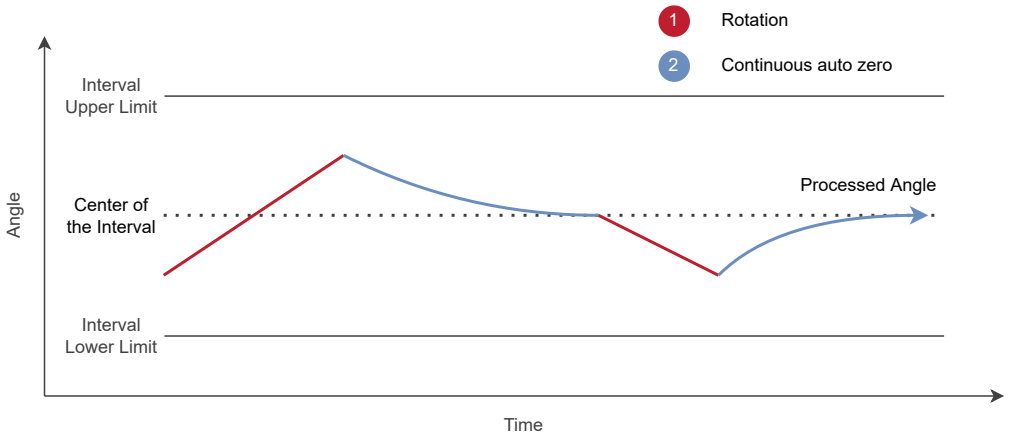


Figure 5.5: Continuous Auto-zero Behaviour

5.12 Quadrature Output

The quadrature output provides feedback over two GPIOs (QUAD0 and QUAD1) when the value of the current interval changes. This functionality can be used for standalone applications where the master device would not need to poll the current interval value over I^2C but would rather monitor the state of the two quadrature outputs. A visual example of the quadrature output is displayed in Figure 5.6.

A single interval change is represented by a rising or falling edge on both quadrature pins. The direction of the interval change is defined by which pin changes state first. For a positive rotation, the state of QUAD0 changes first, and for a negative rotation, the state of QUAD1 changes first. The period between the change in states of each quadrature output is defined by the **quadrature flank delay** parameter. The quadrature flank delay parameter will also define the maximum report rate of the quadrature output.

The quadrature output pins can be configured as either push-pull or open-drain by setting the **quadrature mode** parameter. If open-drain mode is used, pull-up resistors must be added to the quadrature lines as shown in the reference schematic in Section 2.5.

Note: The quadrature output can be fed directly into a standard quadrature decoder. Please note that, since some quadrature decoders expect only one GPIO edge per interval (instead of two), they will record twice the number of intervals.

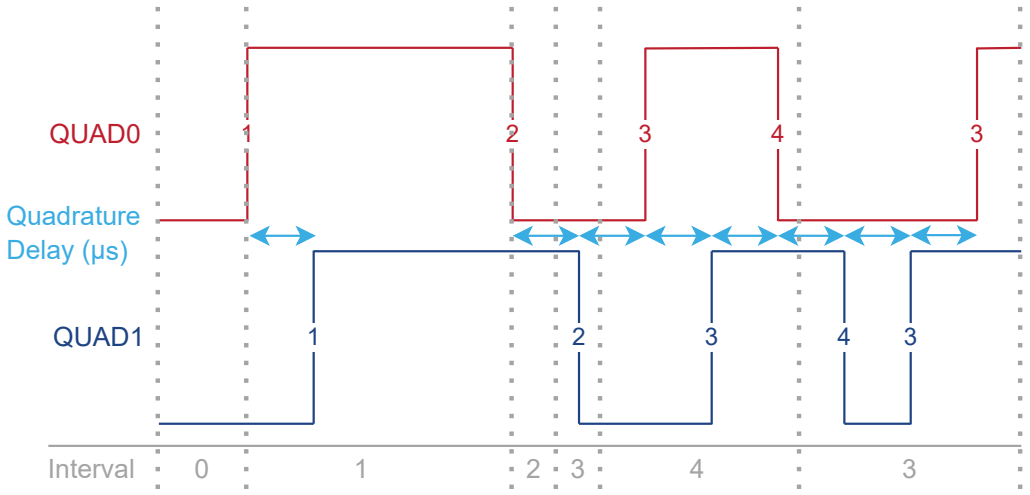


Figure 5.6: Quadrature IO Timing with Respect to Current Interval

Note the rapid change from interval 2 to 4 in Figure 5.6 resulting in a delayed output of the corresponding flanks, so as not to overwhelm the receiving IC.

5.13 Buffered Intervals

During fast rotation, the rate at which intervals are processed may exceed the rate at which quadrature pulses are clocked out. These intervals are buffered in the missed intervals register, and are processed by the quadrature output peripheral at a later time. The buffered intervals can automatically be discarded when the device becomes stationary by setting the discard intervals bit in the **Hall UI settings** register.

6 ProxFusion® Capacitive Sensor Module

The IQS7221E contains a single capacitive sensing channel that uses the patented technology on one of the two ProxFusion® modules on the device to measure and process capacitive sensor data.

6.1 Capacitive Channels

Mutual-capacitive and self-capacitive designs are possible with the IQS7221E. Please refer to the following application notes for more information:

- AZD004: Overview of Azoteq's ProxFusion® Sensing
- AZD125: Design Guidelines for Capacitive Touch Sensing

6.2 Count Value

Capacitive sensing measurements return **counts values** for the single channel of the device. Count values are inversely proportional to the measured capacitance, and all outputs are derived from this value.

The counts measured are limited to a range defined by the **maximum counts** parameter. If a result outside the range is measured, the maximum value will be returned.

The **raw count values** sampled are filtered with multiple beta filters to produce **filtered count values** and **long-term average count values**. The **button beta** parameters define the beta values for calculating the filtered count values in normal and low power modes.

6.3 Reference Value / Long-Term Average (LTA)

User interaction is detected by comparing the measured count values to a reference value. The reference value of a channel is slowly updated to track changes in the environment and is not updated during user interaction.

The signed **delta value** stores the difference between the filtered counts and the reference channel. This value is used to detect user interaction and will cause button events if it exceeds the thresholds defined by the **proximity** and **touch** threshold parameters.

The filter used to calculate the long-term average signal of the channel is defined by the **button LTA beta** and **button fast LTA beta** parameters. The device will select an appropriate beta filter depending on the current power mode and the delta value of the channel. If the delta value is greater than the **fast bound** parameter in the opposite direction of a delta caused by touch, the LTA will be calculated using the fast LTA beta filter.

The reference value of a channel needs to accurately define the environment of the device to detect a user interaction and requires a method of re-evaluating the environment if an invalid state is entered. The reseed function of the device will replace the long-term average value of the channel with the latest sampled counts value to reset the environmental reference of the channel. A **reseed** command can be given by setting the corresponding bit.

6.4 Automatic Tuning Implementation (ATI)

The ATI is a sophisticated technology implemented in ProxFusion® devices to allow optimal performance of the devices for a wide range of sensing electrode capacitances, without modification to external components. The ATI settings allow tuning of various parameters. For a detailed description of ATI, please contact Azoteq.

The ATI for touch channels functions by using the **base** and **target** parameters to calculate appropriate **multiplier** and **compensation** values to achieve an LTA equal to the ATI target value.

6.5 Automatic Re-ATI

One of the most important features of the Re-ATI functionality of the IQS7221E is that it allows easy and fast recovery from an incorrect ATI, such as when performing ATI during user interaction with the sensor. It is recommended to always have the automatic Re-ATI functionality enabled. When a Re-ATI is performed on the IQS7221E, a status bit will be set momentarily to indicate that this has occurred.

An automatic Re-ATI operation is performed when the reference of a channel drifts outside the acceptable range around the ATI Target, which is defined by the **ATI band fraction** parameter. The boundary for the reference to drift is defined in Equation (5).

$$\text{Re-ATI Boundary} = \text{ATI Target} \times \frac{\text{ATI Band Fraction}}{128} \tag{5}$$

For example, if the ATI Target is selected as 1000 counts and the ATI Band Fraction is selected as 20, an ATI event would be activated if the reference drifted to a value greater than 1158 or less than 842.

6.6 Button Events

All button events can be observed by reading the **touch event states** register at I^2C address *0x13*.

Touch and proximity events are triggered when the channel **delta** exceeds the thresholds configured in the **proximity** and **touch** threshold parameters. The sign of the delta will determine the value of the direction flag under **touch event states**. An example of the touch channel's filtered, LTA, and delta response for an LTA beta of 4, and with the release UI enabled, is displayed in Figure 6.1 and Figure 6.2.

Note: Figure 6.1 and Figure 6.2 only displays the behaviour of the device with the release UI enabled.

6.7 Dormancy

The touch dormancy flag will be set if the dormancy timeout event occurs after no touch input is received for the period defined in the **dormancy timeout** parameter.

6.8 Debounce

The debounce flag will be set if the counts have exceeded the proximity threshold, but have not yet exceeded the touch threshold. The debounce event will continue until a set number of cycles have passed, after which the proximity flag will be set. The debounce timeout will be bypassed if the counts exceed the touch threshold. The device will enter high-accuracy mode when the debounce flag is set.

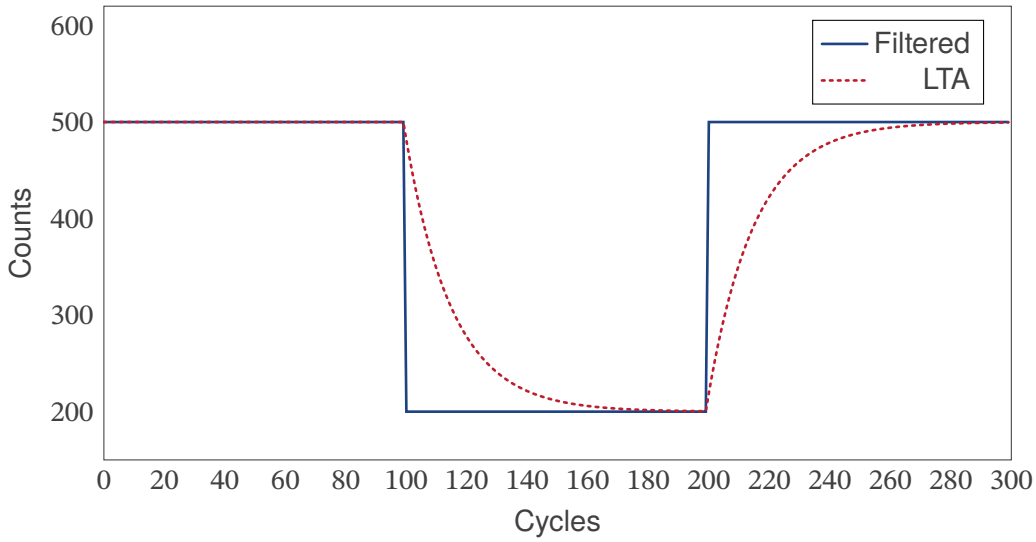


Figure 6.1: Channel Filtered Counts and LTA Response during a Touch Event, with the Release UI Enabled

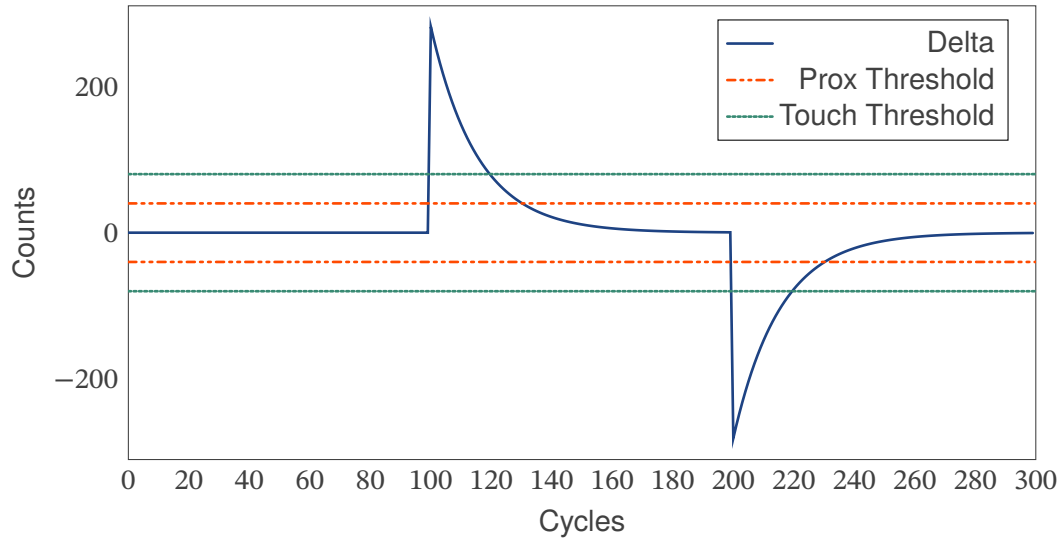


Figure 6.2: Channel Delta Response during a Touch Event

6.9 Release UI

The button UI of the device can sense both touch and release user interactions. The **release UI** bit will determine the behaviour of the reference channel during touch. If the bit is set the device will continue to update the reference channel of the device during a touch event. This will result in a positive touch delta when a touch event occurs and will result in a negative touch delta if a release event occurs. This can be viewed in Figure 6.2.

If the **release UI** bit is cleared the device will not update the reference channel of the device during a touch event. This will cause the touch delta to remain high during the touch event. The touch delta will then return to zero as the touch is released.

The **dual threshold** bit must be set for both negative and positive touch deltas to trigger a touch event.

7 Power Options

The IQS7221E offers 5 power modes:

- High-accuracy (HA)
  - Highest current consumption
  - Must always be configured to have the fastest report rate
  - High-accuracy mode is always entered during:
    - ATI event
    - Touch debounce
  - When in automatic power mode, high-accuracy mode is entered when:
    - The rotation sampled by the Hall effect sensor is fast enough for the **filter switch delta** threshold to be surpassed.
    - The **interval** value has changed.
    - A freewheeling event occurs with the **force high-accuracy** option enabled.
- Normal power mode (NP)
  - The default operating power mode
  - When in automatic power mode, normal power mode is entered when:
    - Exiting high-accuracy mode after the high-accuracy timeout
    - Touch event
    - Prox event
- Low power mode (LP)
  - Lower current consumption than normal power
  - Must be configured to have a slower report rate than normal power
  - When in automatic power mode, low power mode is entered when:
    - Hall stationary timeout event occurs
    - Touch dormancy timeout event occurs
- Ultra-low power mode (ULP)
  - Recommended being configured for the slowest report rate.
  - The sampling rate of the device in ULP is defined by the ULP report rate, but the **auto prox cycles** will define the number of samples before an I^2C communication window is opened.
  - ULP mode will only sample the single touch channel of the device. The device will exit ULP mode if a touch event occurs. ULP must not be enabled if the touch functionality of the device is disabled.
  - The device will only enter ULP if the *ULP enable* bit is set in the **system settings** register.
  - Hall channels will not be sampled when the device is in ULP mode.
  - The device will not enter ULP if there are missed intervals that need to be processed.
  - The device will enter ULP mode if the **ULP timeout event** occurs. The ULP timer is started when the device enters LP mode.
- Halt power mode
  - Is entered and exited by an I^2C command
  - Places device in I^2C standby mode
  - No analog sampling events occur during halt mode
  - Entering halt mode safely requires the manual configuration of a **WDT timeout** of more than 4000 ms.
  - To exit halt mode the master device must open a forced communications window and select an alternative power mode for the IQS7221E.

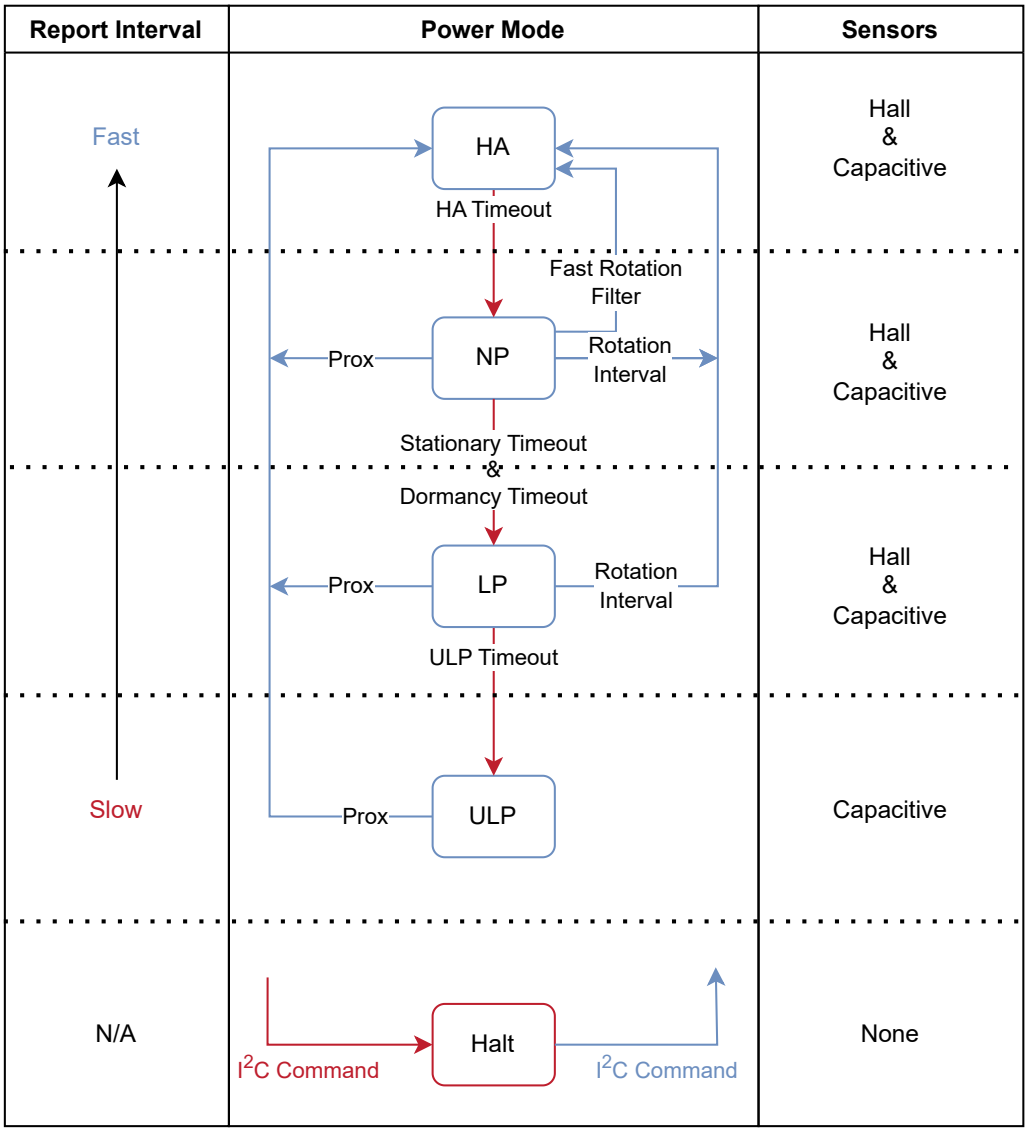


Figure 7.1: Power Modes

8 Additional Features

8.1 Freewheel UI

The freewheeling UI of the IQS7221E allows the device to continue emulating rotational input when no physical rotation is detected by the Hall effect sensor. The freewheeling functionality of the device will continue to update the final angle and the current interval of the device at the rotational speed which was sampled from the Hall effect sensor during physical rotation. This speed will eventually decay until the freewheeling event has ended and no emulated response is produced. This feature of the device is targeted at mouse scroll-wheel applications.

A freewheeling event can occur when the freewheeling UI is enabled and a touch release event occurs when the rotational speed of the physical input is greater than the **freewheeling start speed**. Freewheeling continues until the freewheeling speed decays below the value defined in the **freewheeling stop speed** parameter.

The touch release delta required to start a freewheeling event is defined by the **forward release** and **reverse release** parameters. These parameters are used to set different touch release sensitivity values for freewheeling in different directions.

Freewheeling can manually be stopped during the emulated rotation by triggering a touch event. The **freewheeling touch stop** parameter will determine the touch delta required to stop freewheeling.

8.1.1 Effects of Freewheel Parameters

A simplified equation of the effect of freewheeling on the angular velocity is displayed in Equation (6).

$$\omega_{n+1} = \omega_n - \frac{\text{Friction} + (\text{Damping} \times \omega_n)}{\text{Inertia}}. \tag{6}$$

Figure 8.1 displays the change in angular velocity as the freewheeling friction parameter changes. Freewheeling damping remains constant with a value of 5000 and freewheeling inertia remains constant at 150.

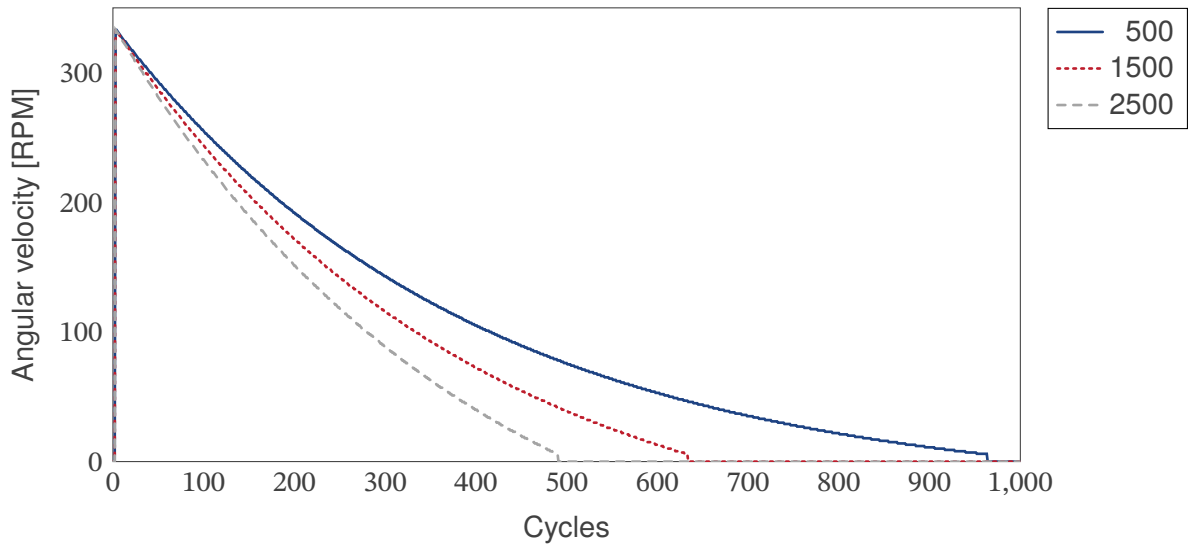


Figure 8.1: Freewheel Response as Friction Changes

Figure 8.2 displays the change in angular velocity as the freewheeling damping parameter changes. Freewheeling friction remains constant with a value of 1000 and freewheeling inertia remains constant at 150.

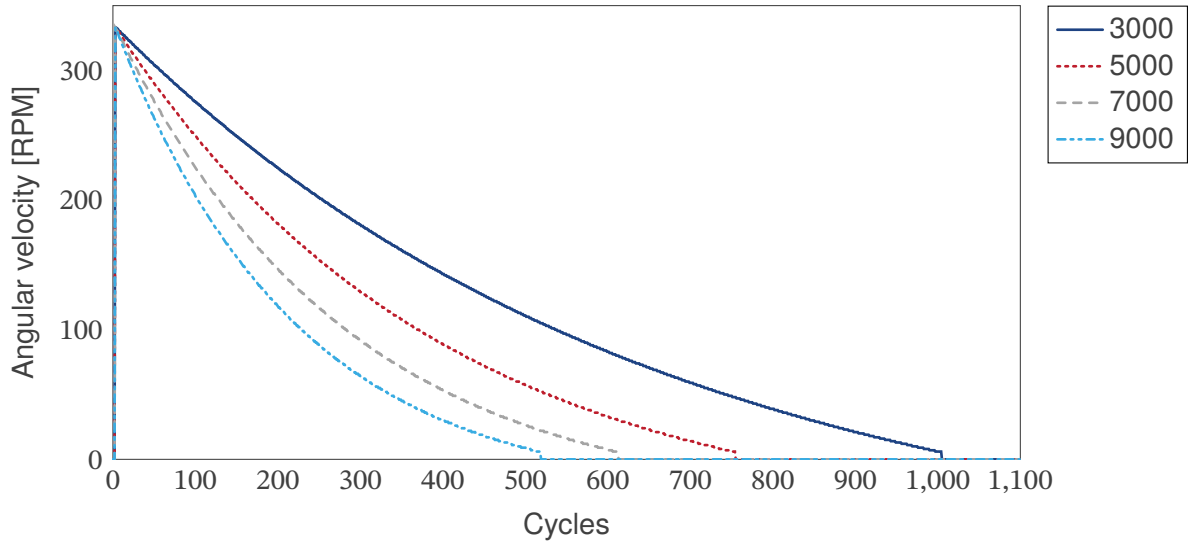


Figure 8.2: Freewheel Response as Damping Changes

Figure 8.3 displays the change in angular velocity as the freewheeling inertia parameter changes. Freewheeling damping remains constant with a value of 5000 and freewheeling friction remains constant at 1000.

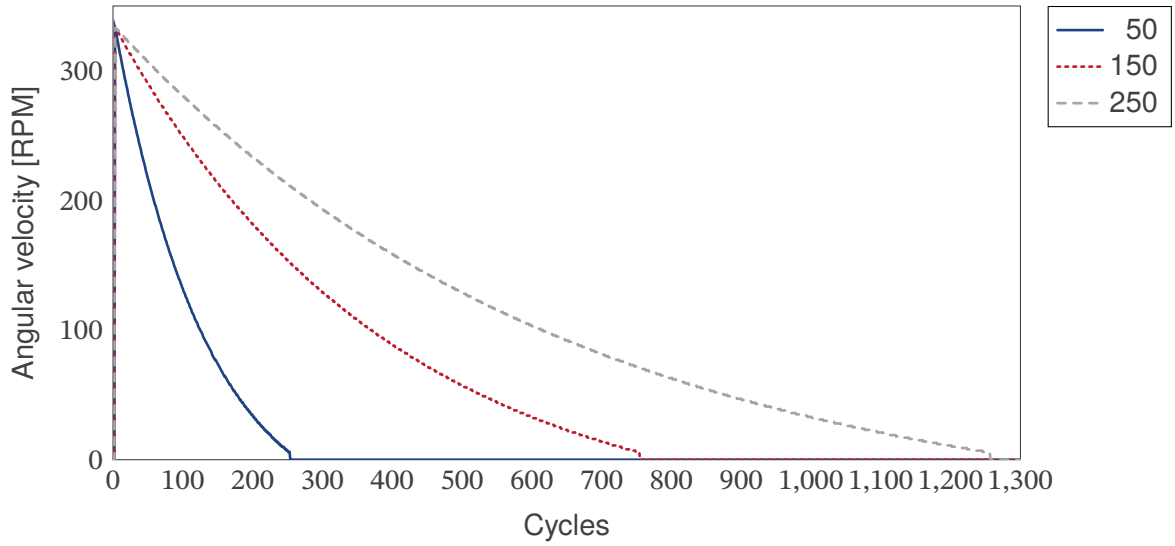


Figure 8.3: Freewheeling Response as Inertia Changes

8.2 Watchdog Timer (WDT)

A software watchdog timer is implemented to improve system reliability. The watchdog timer is reset at the start of the main loop, before any measurements take place. If the timer expires, the device is reset, performing a soft reboot. The **watchdog timeout** register determines the period of the timer in milliseconds before the device will reset.

Note: Ensure that the watchdog timeout period is greater than the I^2C timeout period.

8.3 Reset

8.3.1 Reset Indication

After a reset, the **device reset** bit will be set by the system to indicate the reset event occurred. This device reset bit will clear when the master sets the **ack reset** bit. If the device reset bit becomes set again, the master will know a reset has occurred and can react appropriately.

8.3.2 Software Reset

The IQS7221E can be reset by means of an I^2C command. The **soft reset** bit in the **system settings** register must be set for the device to reset.

8.4 RF Immunity

The IQS7221E offers some immunity to high power RF noise. To improve the RF immunity, extra decoupling capacitors are suggested on VREGA, VREGD, and VDD.

Place a 100 pF in parallel with the 2.2 µF ceramic capacitor on VREGA and VREGD. Place a 4.7 µF ceramic capacitor on VDD, along with an optional parallel 100 pF capacitor. All decoupling capacitors should be placed as close as possible to the VDD and VREG pads.

If needed, series resistors can be added to the Rx electrodes that are used to reduce RF coupling into the sensing pads. Normally these are in the range of 470 Ω – 1 kΩ.

PCB ground planes also improve noise immunity.

8.5 Version Information

Please refer to the **version information table**.

9 Implementation and Layout

9.1 Layout Fundamentals

NOTE

Information in the following Applications section is not part of the Azoteq component specification, and Azoteq does not warrant its accuracy or completeness. Azoteq's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

9.1.1 Power Supply Decoupling

Azoteq recommends connecting a combination of a 4.7 µF plus a 100 pF low-ESR ceramic decoupling capacitor between the VDD and VSS pins. Higher-value capacitors may be used but can impact supply rail ramp-up time. Decoupling capacitors must be placed as close as possible to the pins that they decouple (within a few millimetres).

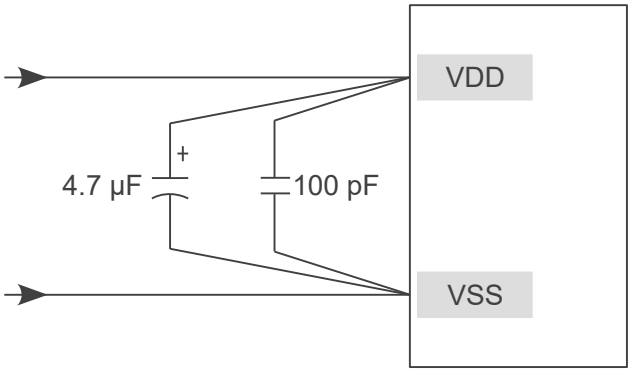


Figure 9.1: Recommended Power Supply Decoupling

9.1.2 VREG Capacitors

Each VREG pin requires a 2.2 µF capacitor to regulate the LDO internal to the device. This capacitor must be placed as close as possible to the IC. The figure below shows an example placement of the VREG capacitors.

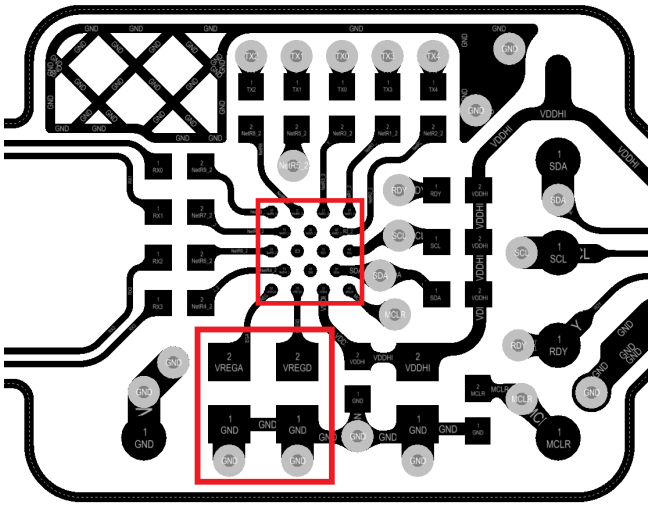


Figure 9.2: VREG Capacitor Placement Close to IC

9.1.3 WLCSP Light Sensitivity

The CSP package is sensitive to infrared light. When the silicon IC is subject to the photo-electric effect, an increase in leakage current is experienced. Due to the low power consumption of the IC this causes a change in signal and is common in the semiconductor industry with CSP devices.

If the IC could be exposed to IR in the product, then a dark glob-top epoxy material should cover the complete package to block infrared light. It is important to use sufficient material to completely cover the corners of the package. The glob-top also provides further advantages such as mechanical strength and shock absorption.

10 I²C Interface

10.1 I²C Module Specification

The device supports a standard two-wire I²C interface with the addition of a RDY (ready interrupt) line. The communications interface of the IQS7221E supports the following:

- *Fast-mode-plus* standard I²C up to 1 MHz.
- Streaming data as well as event mode (Section 10.11).
- Interrupt line (RDY), an open-drain active low GPIO indicates a communication window (Section 10.7).

The IQS7221E implements 8-bit addressing with 2 data bytes at each address. Two consecutive read/writes are required in this memory map structure. The two bytes at each address will be referred to as “byte 0” (least significant byte) and “byte 1” (most significant byte).

10.2 I²C Starting Behaviour

The device will default to streaming mode when the **device reset** bit is set. For the device to communicate as defined in the system settings, the **acknowledge reset** bit needs to be set.

10.3 I²C Address

The default 7-bit device address is `0x56` (`0b1010110`). The full address byte will thus be `0xAD` (read) or `0xAC` (write).

I²C address `0x53` is available with order code IQS7221E002*ppb*. Other address options exist on special request. Please contact Azoteq.

10.4 I³C Compatibility

This device is not compatible with an I³C bus due to clock stretching allowed for data retrieval.

10.5 Memory Map Addressing

The memory map implements an 8-bit addressing scheme for the required user data.

10.6 Data

The data is stored in 16-bit words, meaning that each address contains two bytes of data. For example, address 0x10 will provide two bytes, then the next two bytes read will be from address 0x11. The 16-bit data is sent in little endian byte order (least significant byte first).

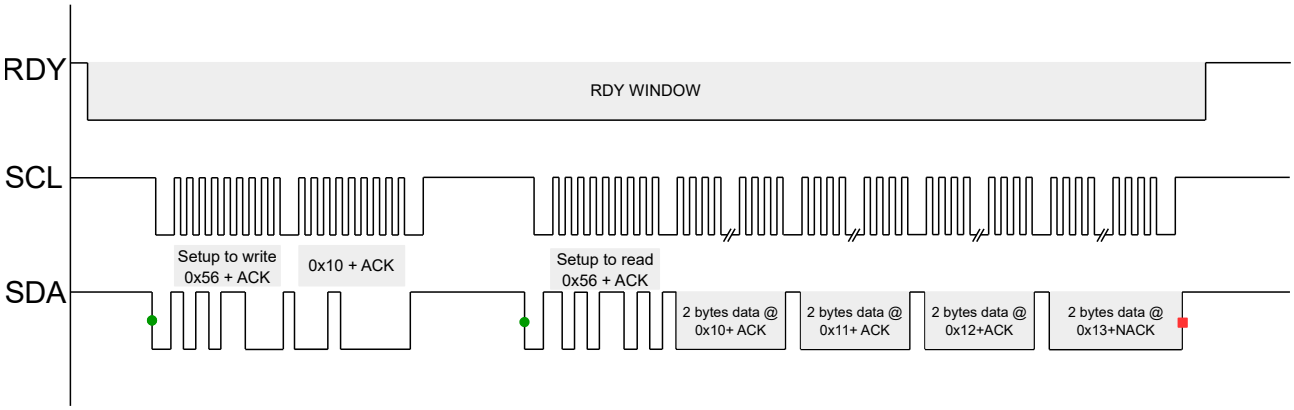


Figure 10.1: Example of Reading Data over I²C

The IQS7221E GUI can generate a C header file (*.h* file) that stores the values of all the read-write registers of the IQS7221E. The *.h* file will display the start address of each block of data, with each address containing 2 bytes. The data of all the addresses can be read or written consecutively in a single block of data, as shown in Figure 10.1. An example of the h file exported by the GUI and the order of the data, is shown below.

```
/* Change the Global Device Settings */
/* Memory Map Position 0x60 - 0x6F */              // Shows starting address
#define UI_SETTINGS                          0x11  // LSB
#define UI_SETTINGS_1                        0x09  // MSB
...
```

10.7 RDY/IRQ

The IQS7221E has an open-drain active low RDY signal to inform the master that updated data is available. The IQS7221E will pull the RDY line low to indicate that it has opened a communications window, or “RDY window”, for the master to read the new updated data. Once the I²C transactions have completed, and an I²C stop condition is detected, the RDY line is released and the comms window is closed. The IQS7221E will then go to sleep or continue with a new sensing cycle.

I²C communication can only be performed while the RDY window is open. The IC will respond with an error code (`0xEE`) if communication is attempted while RDY is high. The master can however request a new RDY window using the **Force Communication** method, if necessary.

It is optimal for the master to use this RDY as an interrupt input and obtain the data accordingly. It is also useful to allow the master MCU to enter low power or sleep mode, allowing the IQS7221E’s RDY interrupt to wake the device when user presence is detected. The RDY pin should ideally be connected to an interrupt-on-pin-change input on the master.

Enabling **Event Mode** will set the RDY pin to trigger only when any significant events occur, such as touch events or interval changes. The device can also be placed in **Standalone Mode**, disabling all RDY notifications. However, quadrature outputs are still enabled in both standalone mode and event mode.

10.8 I²C Timeout

If a communication window is not serviced within the **I²C Transaction Timeout** period, the session is ended (RDY goes HIGH), and processing continues as normal. This allows the system to continue and keep reference values up to date even if the master is not responsive. However, the corresponding data will be lost, so this should be avoided. The default I²C timeout period is set to 500 ms.

10.9 Terminate Communication

A standard I²C STOP ends the current communication window.

If the **Stop Ends Comms Disable** bit is set, the device will not close the communication window on a standard I²C STOP. Instead, the communication window must be terminated using the end communications command (`0xFF`), as shown in Figure 10.2.

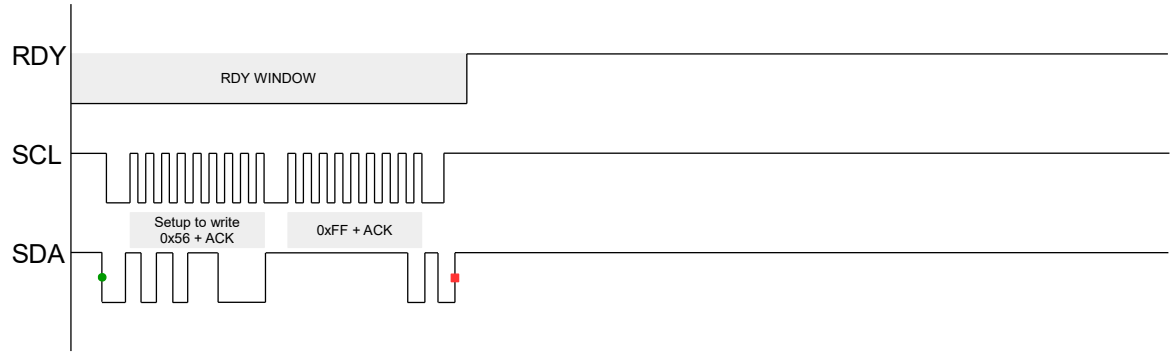


Figure 10.2: Force Stop Communication Sequence

10.10 Invalid Communications Return

The device will give an invalid communication response (`0xEE`) under the following conditions:

- The host is trying to read from a memory map register that does not exist.
- The host is trying to read from the device outside a communication window (while RDY is high).

10.11 I²C Interface

The IQS7221E has two I²C interface options, as described in the sections below.

10.11.1 I²C Streaming

I²C streaming mode refers to constant data reporting at the relevant power mode report rate specified in the **report rate registers**. The IQS7221E will pull the RDY line low to open a new communication window at the end of every single cycle. This mode is useful when streaming the device in the accompanying debug software.

10.11.2 I²C Event Mode

The device can be set up to bypass the communication window when no activity is sensed. This is usually enabled since the master does not need to be interrupted unnecessarily during every cycle if no activity has occurred, reducing current consumption. The device will provide a communications window when one of the enabled events occurs.

Event mode is described in more detail in Section 10.12.

10.12 Event Mode Communication

Event mode can only be entered if the following requirements are met:

- Events must be serviced by reading from the **global events** register to ensure all events flags are cleared, otherwise continuous reporting (RDY interrupts) will persist after every cycle, similar to streaming mode.
- The **device reset** bit has been cleared by setting the **ACK reset** bit.

10.12.1 Events

Numerous events can be individually enabled to trigger communication. Bit definitions can be found in Table A.9.

- Power mode change
- Prox and touch events
- ATI event
- Hall events

10.12.2 Force Communication

In streaming mode, the IQS7221E I²C will provide RDY windows at regular intervals specified by the relevant power mode report rate. This will provide the master with regular opportunities to perform I²C communication as necessary.

If the device is placed in Event Mode, Standalone Mode, or Halt mode, the IQS7221E will not open RDY windows unless certain conditions are met. A new RDY window can be requested by writing `0xFF` over I²C, followed by a stop condition. After a short delay, the IQS7221E will pull the RDY line low and open a new communication window. This is shown in Figure 10.3.

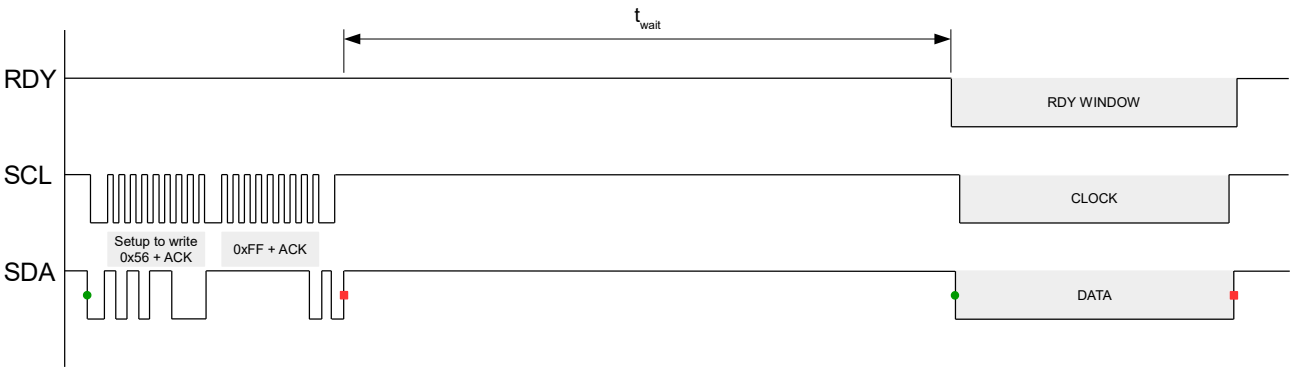


Figure 10.3: Force Communication Sequence

The minimum and maximum time between the communication request and the opening of a RDY window (t_{wait}) is application specific, but the average values are 0.1 ms ≤ t_{wait} ≤ 45 ms[i].

[i] Please contact Azoteq for an application specific value of t_{wait}.

11 I²C Memory Map

See Appendix A for more detailed descriptions of registers and bit definitions.

The IQS7221E uses two's complement to represent signed values.

Table 11.1: I²C Memory Map Read-Only Registers

Address	Data (16-bit)	Notes
	VERSION INFORMATION	
0x00 – 0x02	Version details	See Table A.1
	SYSTEM STATUS AND FLAGS	
0x10	System Status	See Table A.2
0x11	Global Events	See Table A.3
0x12	Hall UI Flags	See Table A.4
0x13	Touch Event States	See Table A.5
0x14	Freewheel UI Flags	See Table A.6
	HALL UI DATA	
0x20	Interval	16-bit value
0x21	Processed Angle	0 – 65535
0x22	Absolute Angle	
0x23	Field Differential A0-B1	32-bit signed value (LSB First)
0x24		
0x25	Field Differential A1-B0	
0x26		
0x27	Interval Upper Limit	16-bit value
0x28	Interval Lower Limit	
	CHANNEL COUNTS	
0x40	Raw Button Counts	16-bit value
0x41	Filtered Button Counts	
0x42	Button LTA	
0x43	Button Delta	Signed 16-bit
0x44	Hall Reference A0	16-bit value
0x45	Hall Reference B1	
0x46	Hall Reference A1	
0x47	Hall Reference B0	
0x48	Hall Plate A0 Normal Counts	
0x49	Hall Plate A0 Inverted Counts	
0x4A	Hall Plate B1 Normal Counts	
0x4B	Hall Plate B1 Inverted Counts	
0x4C	Hall Plate A1 Normal Counts	
0x4D	Hall Plate A1 Inverted Counts	
0x4E	Hall Plate B0 Normal Counts	
0x4F	Hall Plate B0 Inverted Counts	
	FREEWHEEL DATA	
0x53	Magnet Filtered Speed	16-bit value
0x54	Freewheel Speed	
0x55	Reserved	
0x56	Magnet Movement During Freewheeling	

Table 11.2: I²C Memory Map Read-Write Registers

Address	Default	Data (16-bit)	Notes
		SYSTEM AND REPORT-RATE SETTINGS	
0x60	0x6911	System Settings	See Table A.7
0x61	0x0000	I²C Settings	See Table A.8
0x62	0x0005	High-accuracy Mode Report Rate	16-bit value
0x63	0x0028	Normal Power Report Rate	
0x64	0x00C8	Low Power Report Rate	
0x65	0x01F4	Ultra-low Power Report Rate	
0x66	0x7530	ULP Timeout	
0x67	0x001D	Event Mask	See Table A.9
0x68	0x0064	Quadrature Flank Delay	16-bit value
0x69	0x0002	Quadrature Mode	See Table A.10
0x6A	0x03E8	Watchdog Timeout	16-bit value
0x6B	0x0000	Hall Stabilisation Delay	
		HALL UI SETTINGS	
0x70	-	Wheel-to-Magnet Angle Offset	16-bit value
0x71	-	Reserved	
0x72	0x03E8	Filter Switch Delta	
0x73	-	Reserved	
0x74	0x00FA	Interval Hysteresis	
0x75	0x0018	Number of Intervals	
0x76	0x012C	High-accuracy Timeout	
0x77	0x1388	Stationary Timeout	
0x78	0x0205	Filter Betas	See Table A.11
0x79	0x0101		See Table A.12
0x7A	0x0106	UI Settings	See Table A.13
		HALL PLATE SETTINGS	
0x80	0x05E2	Hall Plate Fine and Coarse Multipliers	See Table A.14
0x81	0x05E2		
0x82	0xDBDB	Hall Plate Bias	See Table A.15
0x83	0xDBDB		See Table A.16
0x84	-	Hall Plate Offsets	See Table A.17
0x85	-		See Table A.18
		FREEWHEEL SETTINGS	
0x90	0x0204	Filter Betas	See Table A.19
0x91	0x0014	Freewheel Friction	16-bit value
0x92	0x1388	Freewheel Damping	
0x93	0x00FF	Freewheel Inertia	
0x94	0x0028	Freewheel Starting Speed	
0x95	0x0014	Freewheel Stop Speed	
0x96	-	Reserved	
0x97	-		
0x98	0x1414	Freewheel Touch Thresholds	See Table A.20
0x99	0x0014		See Table A.21
0x9A	0x0AAA	Movement Stop Threshold	16-bit value
0x9B	0x0028	Stationary Detection Speed	
		HALL ATI SETTINGS	
0xA0	0x00C8	Target Min	16-bit value
0xA1	0x012C	Target Max	
0xA2	0x0203	ATI Settings	See Table A.22

Table 11.2: (continued)

Address	Default	Data (16-bit)	Notes
		BUTTON SETTINGS	
0xB0	0x0FA0	Prox Timeout	16-bit value
0xB1	0x9C40	Touch Timeout	
0xB2	0x0FA0	Dormancy Timeout	
0xB3	0x03E8	ATI Timeout	
0xB4	0x0102	Counts Betas	See Table A.23
0xB5	0x0708	LTA Betas	See Table A.24
0xB6	0x0304	Fast LTA Betas	See Table A.25
0xB7	0x1005	Button Reseed Settings	See Table A.26
		BUTTON SENSOR SETTINGS	
0xC0	0x7F05	Button Control 0	See Table A.27
0xC1	0x1A10	Button Control 1	See Table A.28
0xC2	0x0001	CTx Select	See Table A.30
0xC3	0xCF15	Button settings	See Table A.31
0xC4	0x0064	ATI Base	16-bit value
0xC5	0x01F4	ATI Target	
0xC6	-	Button Fine and Coarse Multipliers	See Table A.32
0xC7	-	Button Compensation	See Table A.33
		BUTTON EVENT SETTINGS	
0xD0	0x1214	Prox Threshold	See Table A.34
0xD1	0x3414	Touch Threshold	See Table A.35
		I2C SETTINGS	
0xE0	0x01F4	I^2C Transaction Timeout	16-bit value

12 Ordering Information

12.1 Ordering Code

Table 12.1: Order Code Description

IQS7221E zzz ppb

IC NAME				IQS7221E
CONFIGURATION	zzz	=	001	Supports 18 MHz F_{OSC} I^2C address: 0x56
		=	002	Supports 18 MHz F_{OSC} I^2C address: 0x53
		=	101	Supports 14 MHz and 18 MHz F_{OSC} I^2C address: 0x56
PACKAGE TYPE	pp	=	CS	WLCSP-18 package
		=	QN	QFN-20 package
		=	QF	QFN-20 package
BULK PACKAGING	b	=	R	QFN-20 Reel (2000pcs/reel) WLCSP-18 Reel (3000pcs/reel)

For more information regarding the different configurations, please refer to Section 3.4.

12.2 Top Marking

12.2.1 WLCSP18 Package Marking Option 1

Package outline can be found in Section 13.5.

Product Name
ppp = Product Code
xx = Batch Code

12.2.2 WLCSP18 Package Marking Option 2

Package outline can be found in Section 13.5.

Product Name
ppp = Product Code
xx = Batch Code

12.2.3 QFN20 Package Marking Option 1 (IQS7221EzzzQFR)

Package outline can be found in Section 13.1.

Product Name
ppp = Product Code
xx = Batch Code

12.2.4 QFN20 Package Marking Option 2 (IQS7221EzzzQNR)

Package outline can be found in Section 13.3.

Product Name
ppp = Product Code
xx = Batch Code

13 Package Specification

13.1 Package Outline Description – QFN20 (QFR)

This package outline is specific to order codes ending in *QFR*.

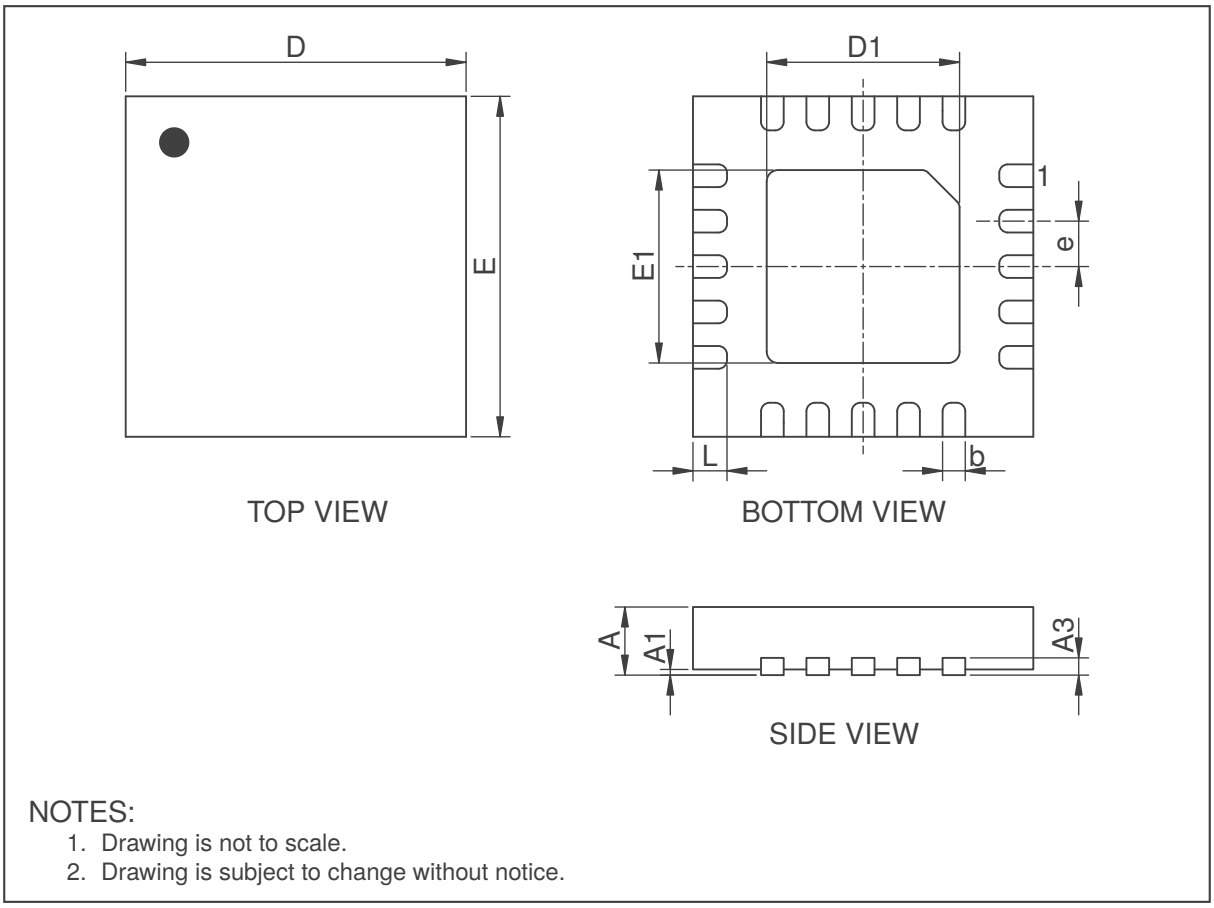
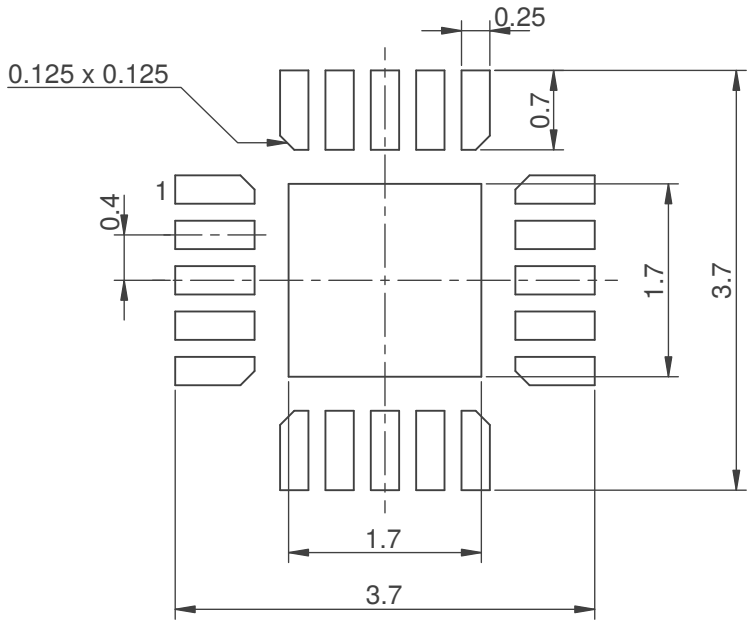


Figure 13.1: QFN (3x3)-20 (QFR) Package Outline Visual Description

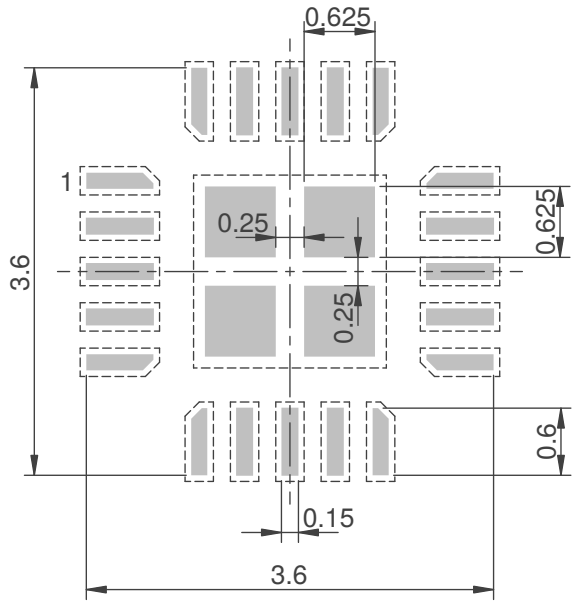
Table 13.1: QFR (3x3)-20 Package Outline Dimensions [mm]

Dimension	Min	Nom	Max
A	0.50	0.55	0.60
A1	0	0.02	0.05
A3		0.152 REF	
b	0.15	0.20	0.25
D		3.00 BSC	
E		3.00 BSC	
D1	1.60	1.70	1.80
E1	1.60	1.70	1.80
e		0.40 BSC	
L	0.25	0.30	0.35

13.2 Recommended PCB Footprint – QFN20 (QFR)



RECOMMENDED FOOTPRINT



RECOMMENDED SOLDER PASTE APPLICATION

NOTES:

1. Dimensions are expressed in millimeters.
2. Drawing is not to scale.
3. Drawing is subject to change without notice.
4. Final dimensions may vary due to manufacturing tolerance considerations.
5. Customers should consult their board assembly site for solder paste stencil design recommendations.

Figure 13.2: QFN (3x3)-20 (QFR) Recommended Footprint

13.3 Package Outline Description – QFN20 (QNR)

This package outline is specific to order codes ending in *QNR*.

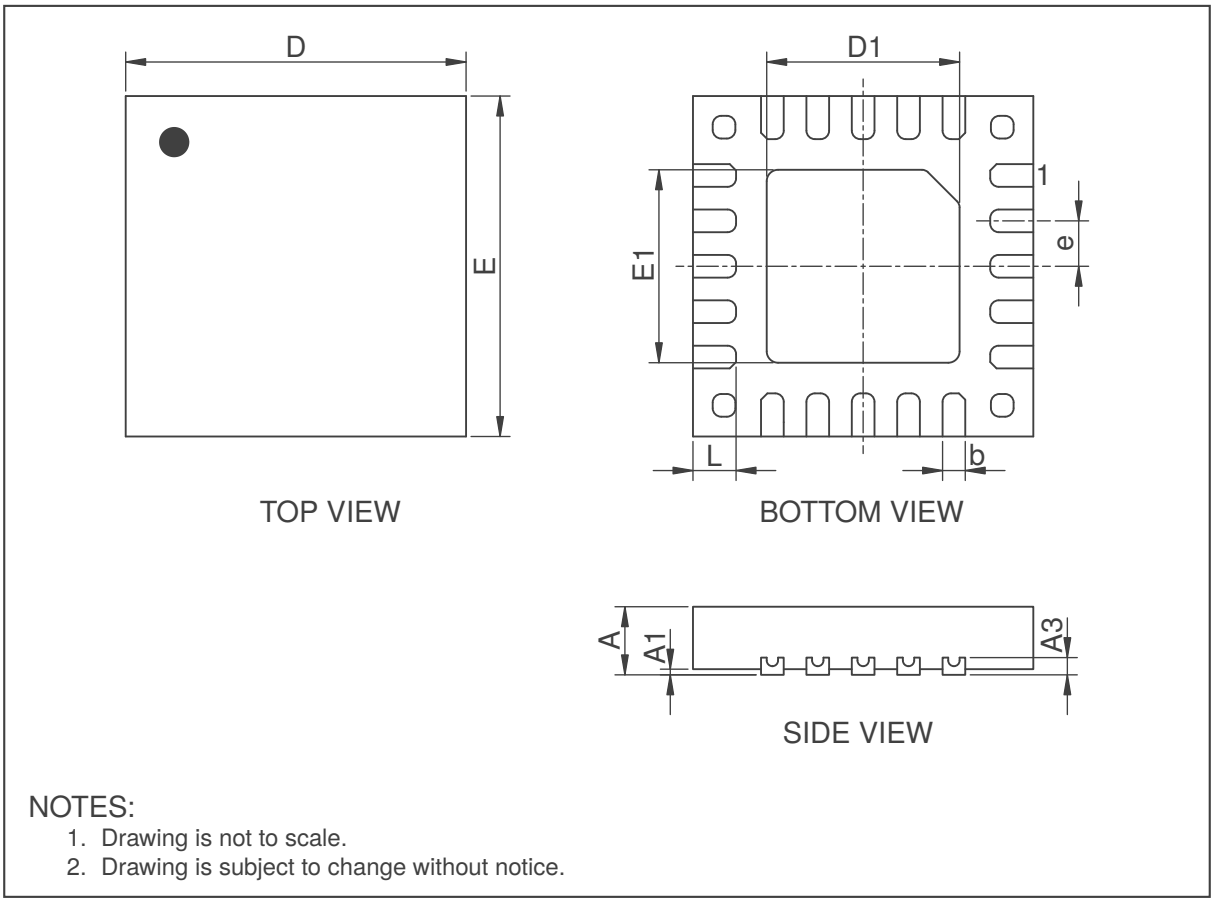
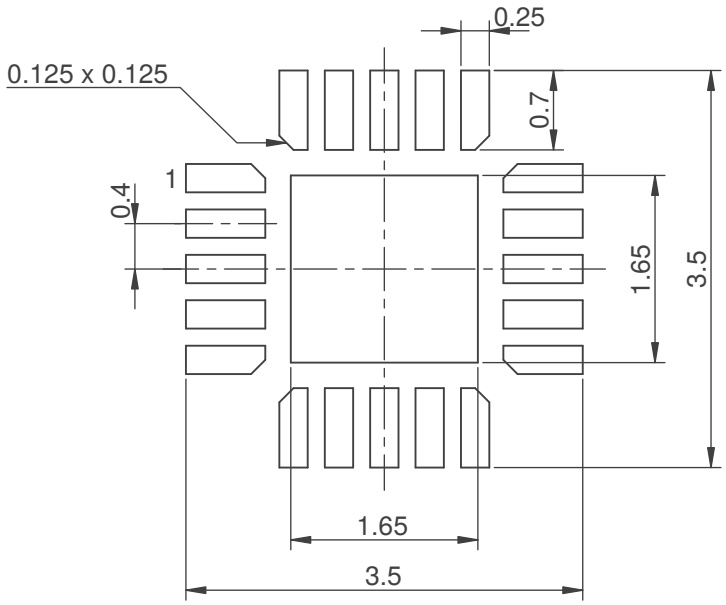


Figure 13.3: QFN (3x3)-20 (QNR) Package Outline Visual Description

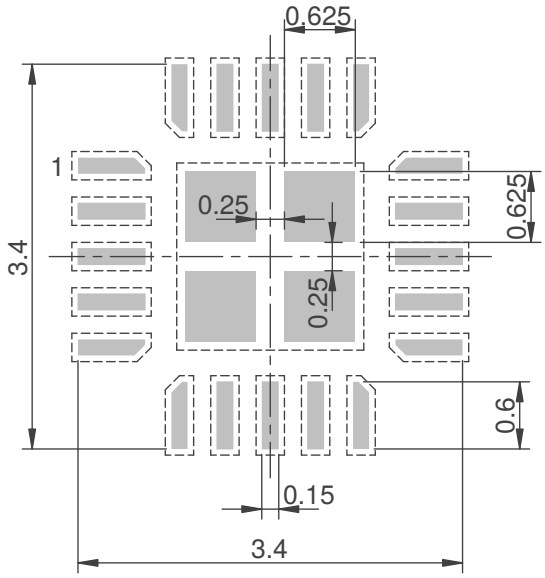
Table 13.2: QNR (3x3)-20 Package Outline Dimensions [mm]

Dimension	Min	Nom	Max
A	0.50	0.55	0.60
A1	0		0.05
A3		0.152 REF	
b	0.15	0.20	0.25
D	2.95	3.00	3.05
E	2.95	3.00	3.05
D1	1.65	1.70	1.75
E1	1.65	1.70	1.75
e		0.40 BSC	
L	0.33	0.38	0.43

13.4 Recommended PCB Footprint – QFN20 (QNR)



RECOMMENDED FOOTPRINT



RECOMMENDED SOLDER PASTE APPLICATION

NOTES:

1. Dimensions are expressed in millimeters.
2. Drawing is not to scale.
3. Drawing is subject to change without notice.
4. Final dimensions may vary due to manufacturing tolerance considerations.
5. Customers should consult their board assembly site for solder paste stencil design recommendations.

Figure 13.4: QFN (3x3)-20 (QNR) Recommended Footprint

13.5 Package Outline Description – WLCSP18

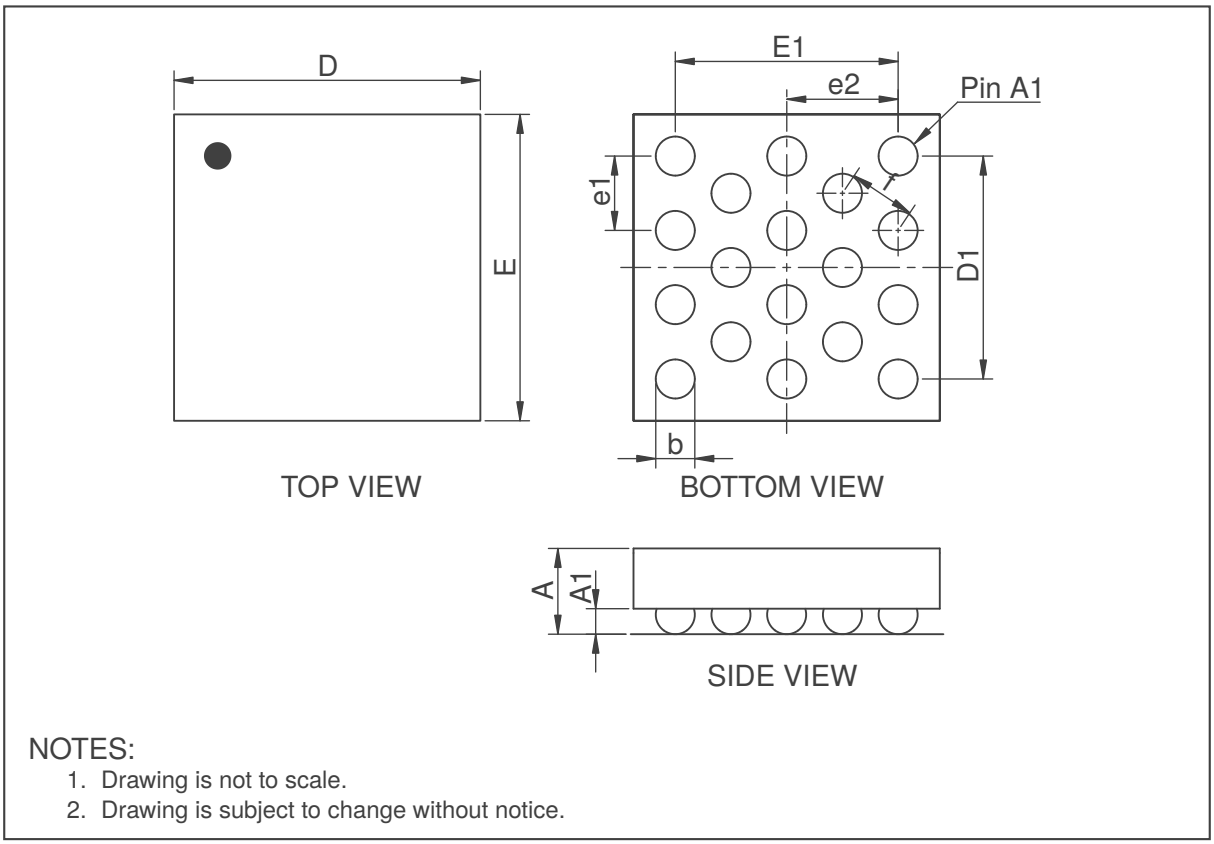
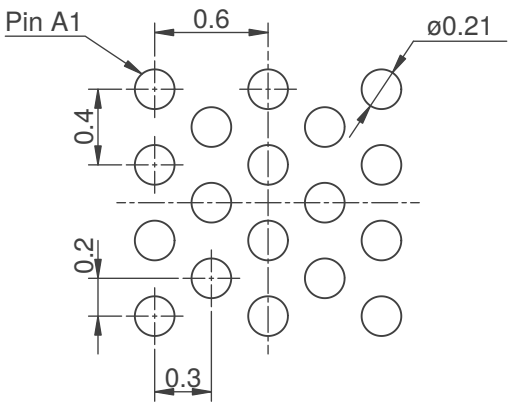


Figure 13.5: WLCSP (1.62x1.62)-18 Package Outline Visual Description

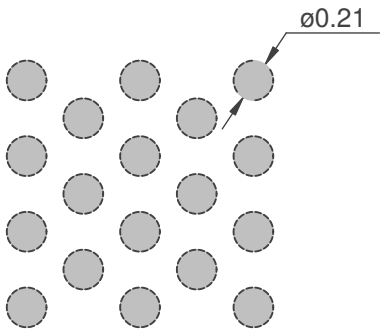
Table 13.3: WLCSP (1.62x1.62)-18 Package Dimensions [mm]

Dimension	Min	Nom	Max
A	0.477	0.525	0.573
A1	0.180	0.200	0.220
b	0.221	0.260	0.299
D	1.605	1.620	1.635
E	1.605	1.620	1.635
D1		1.200 BSC	
E1		1.200 BSC	
e1		0.400 BSC	
e2		0.600 BSC	
f		0.360 REF	

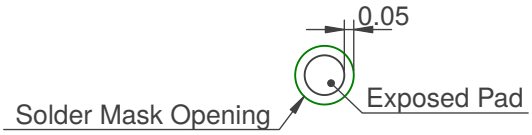
13.6 Recommended PCB Footprint – WLCSP18



RECOMMENDED FOOTPRINT



RECOMMENDED SOLDER PASTE APPLICATION



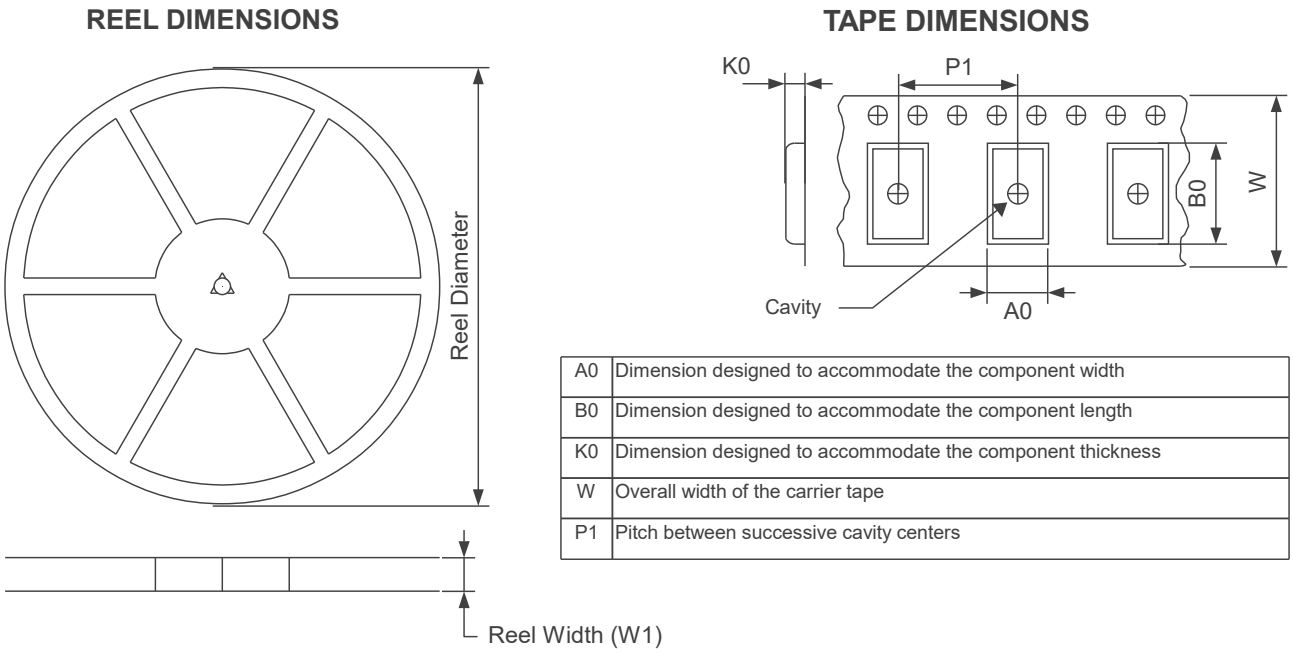
SOLDER MASK BACK-OFF

NOTES:

1. Dimensions are expressed in millimeters.
2. Drawing is not to scale.
3. Drawing is subject to change without notice.
4. Final dimensions may vary due to manufacturing tolerance considerations.
5. Customers should consult their board manufacturer for solder mask tolerances.
6. Customers should consult their board assembly site for solder paste stencil design recommendations.

Figure 13.6: WLCSP18 Recommended Footprint

13.7 Tape and Reel Specifications



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

Figure 13.7: Tape and Reel Specification

Table 13.4: Tape and Reel Specifications

Package Type	Pins	Reel Diameter (mm)	Reel Width (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
QFN20	20	180	12.4	3.3	3.3	0.8	8	12	Q2
WLCSP18	18	179	8.4	1.78	1.78	0.69	4	8	Q1

13.8 Moisture Sensitivity Levels

Table 13.5: Moisture Sensitivity Levels

Package	MSL
QFN20	1
WLCSP18	1

13.9 Reflow Specifications

Contact Azoteq

A Memory Map Descriptions

A.1 Version Information (0x00)

Table A.1: Version Information

Address	Category	Name	Value		
			IQS7221E001	IQS7221E002	IQS7221E101
0x00	Application Version Info	Product Number	1283	1283	1283
0x01		Major Version	1	1	2
0x02		Minor Version	1	2	0

A.2 System Status (0x10)

Table A.2: System Status

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved										Power mode				Reset	ATI Active

- Bit 2-5: **Power Mode**
  - 0: High-accuracy
  - 1: Normal power
  - 2: Low power
  - 4: Ultra low power
  - 8: Halt mode
- Bit 1: **Device Reset**
  - 0: No reset occurred
  - 1: Reset occurred
- Bit 0: **ATI Active**
  - 0: ATI not active
  - 1: ATI active

A.3 Global Events (0x11)

Table A.3: Global Events

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved											Hall Event	Prox Event	Touch Event	ATI Event	Power Event

- Bit 4: **Hall Event**
  - 0: No Hall event occurred
  - 1: Hall event occurred
- Bit 3: **Prox Event**
  - 0: No proximity event occurred
  - 1: Proximity event occurred
- Bit 2: **Touch Event**
  - 0: No touch event occurred
  - 1: Touch event occurred
- Bit 1: **ATI Event**
  - 0: No ATI event occurred
  - 1: ATI event occurred
- Bit 0: **Power Event**
  - 0: No power event occurred
  - 1: Power event occurred

A.4 Hall UI Flags (0x12)

Table A.4: Hall UI Flags

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved										Fast Filter	Low Magnetic Field	High-accuracy	Stationary	Direction	Interval Changed

- Bit 5: **Fast Filter**
  - 0: Fast filter is not active
  - 1: Fast filter is active
- Bit 4: **Low Magnetic Field**
  ** Only applicable to IQS7221E101*
  - 0: Diametric magnetic field present
  - 1: Measured diametric magnetic field stength is too low for accurate Hall-effect rotation sensing. Magnet may not be present.
- Bit 3: **High-accuracy**
  - 0: Device not in high-accuracy mode
  - 1: Device in high-accuracy mode
- Bit 2: **Stationary**
  - 0: Device is not stationary
  - 1: Device is stationary
- Bit 1: **Direction**
  - 0: Reverse rotation sampled
  - 1: Forward rotation sampled
- Bit 0: **Interval Changed**
  - 0: Interval change did not occur
  - 1: Interval change occurred

A.5 Touch Event States (0x13)

Table A.5: Touch Event States

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved				ATI Error	Debounce	Direction	Dormant	Reserved						Touch	Prox

- Bit 11: **ATI Error**
  ** Only applicable to IQS7221E101*
  - 0: Touch channel ATI successful
  - 1: ATI error occurred on the touch channel
- Bit 10: **Debounce**
  - 0: Touch channel not in debounce state
  - 1: Touch channel in debounce state
- Bit 9: **Direction**
  - 0: Negative delta for touch channel
  - 1: Positive delta for touch channel
- Bit 8: **Dormant**
  - 0: Touch channel is not in dormant state
  - 1: Dormancy timeout occurred, and touch channel is in dormant state
- Bit 1: **Touch**
  - 0: Touch event is not active
  - 1: Touch event is active
- Bit 0: **Prox**
  - 0: Prox event is not active
  - 1: Prox event is active

A.6 Freewheel UI Flags (0x14)

Table A.6: Freewheel UI Flags

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved												Touch Exit	Touch Enter	Stationary	Free-wheeling

- Bit 3: **Touch Exit**
  - 0: Touch exit event did not occur
  - 1: Touch exit event occurred
- Bit 2: **Touch Enter**
  - 0: Touch enter event did not occur
  - 1: Touch enter event occurred
- Bit 1: **Stationary**
  - This bit will not be cleared on freewheeling interval change.
  - 0: Device is not stationary
  - 1: Device is stationary
- Bit 0: **Freewheeling**
  - 0: Freewheeling is inactive
  - 1: Freewheeling is active

A.7 System Settings (0x60)

Table A.7: System Settings

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved	Enable ULP	Event Mode	Power Mode					F_{OSC}	Reserved	Comms in ATI	Hall Auto ATI	ACK Reset	Soft Reset	Force ATI	Stream
Default: 0x6911															
0	1	1	0	1	0	0	1	0	0	0	1	0	0	0	1

- Bit 14: **Ultra-Low Power Enable**
  - 0: Device will not enter ultra-low power mode when automatic power mode switching is enabled
  - 1: Device can enter ultra-low power mode when automatic power mode switching is enabled. Only a touch event on Channel 0 will wake the device from ULP mode.
- Bit 13: **Event Mode Enable**
  - 0: I^2C Streaming Mode enabled
  - 1: Event Mode enabled
- Bit 8-12: **Power Mode**
  - 0: High-accuracy mode
  - 1: Normal power mode
  - 2: Low power mode
  - 4: Ultra-low power mode
  - 8: Halt mode[i]
  - 9: Auto power mode
- Bit 7: **F_{OSC} Frequency Selection**
  ** Only applicable to IQS7221E101*
  - 0: 18 MHz
  - 1: 14 MHz
- Bit 5: **Comms in ATI**
  - 0: Comms during ATI is disabled
  - 1: Comms during ATI is enabled
- Bit 4: **Hall Runtime ATI**
  - 0: Hall runtime ATI disabled
  - 1: Hall runtime ATI enabled
- Bit 3: **Acknowledge Reset**
  - 0: No effect
  - 1: Acknowledge reset (Bit cleared automatically after instruction)

[i] Set **WDT timeout** > 4000 ms.

- Bit 2: **Soft Reset**
  - 0: No effect
  - 1: Reset device (Bit cleared automatically after instruction)
- Bit 1: **Force ATI**
  - 0: No effect
  - 1: Execute ATI command (Bit cleared automatically after instruction)
- Bit 0: **Streaming Enable**
  - 0: Enable standalone mode
  - 1: Enable I²C streaming mode

A.8 I²C Settings (0x61)

Table A.8: I²C Settings

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved														RW Check	Stop End Comms
Default: 0x0000															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

- Bit 1: **Read-Write Check Disable**
  - 0: Read-Write check is enabled
  - 1: Read-Write check is disabled
- Bit 0: **Stop Ends Comms Disable**
  - 0: Close I²C communications window on I²C stop condition
  - 1: Keep I²C communications window open until `0xFF` command

A.9 Event Mask (0x67)

Table A.9: Event Mask

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved											Hall Interval Event	Prox Event	Touch Event	ATI Event	Power Mode Event
Default: 0x001D															
0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1

- Bit 4: **Hall Interval Event**
  - 0: Hall interval change event disabled
  - 1: Hall interval change event enabled
- Bit 3: **Prox Event**
  - 0: Proximity event disabled
  - 1: Proximity event enabled
- Bit 2: **Touch Event**
  - 0: Touch event disabled
  - 1: Touch event enabled
- Bit 1: **ATI Event**
  - 0: ATI event disabled
  - 1: ATI event enabled
- Bit 0: **Power Mode Event**
  - 0: Power mode event disabled
  - 1: Power mode event enabled

A.10 Quadrature Mode (0x69)

Table A.10: Quadrature Mode

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved			Encoder 1 State	Encoder 0 State	State			Reserved						Mode	
Default: 0x0002															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

- Bit 12: **Encoder 1 State**
  - 0: Encoder 1 is in the LOW state
  - 1: Encoder 1 is in the HIGH state
- Bit 11: **Encoder 0 State**
  - 0: Encoder 0 is in the LOW state
  - 1: Encoder 0 is in the HIGH state
- Bit 8-10: **Quadrature State**
  - 0: Idle low
  - 1: Idle high
  - 2: Follow wait low
  - 3: Follow wait high
  - 4: Wait next
- Bit 0-1: **Quadrature Mode**
  - 0: Off
  - 1: Open-drain
  - 2: Push-pull

A.11 Hall Filter Betas 0 (0x78)

Table A.11: Filter Betas 0

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Fast Filter Beta								Slow Filter Beta							
Default: 0x0205															
0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1

- Bit 8-15: **Fast Filter Beta**
  - Unsigned 8-bit value
- Bit 0-7: **Slow Filter Beta**
  - Unsigned 8-bit value

A.12 Hall Filter Betas 1 (0x79)

Table A.12: Filter Betas 1

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Auto Zero Beta								Low Power Filter Beta							
Default: 0x0101															
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1

- Bit 8-15: **Auto Zero Beta**
  - Unsigned 8-bit value
- Bit 0-7: **Low Power Filter Beta**
  - Unsigned 8-bit value

A.13 Hall UI Settings (0x7A)

Table A.13: Hall UI Settings

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved							Hall UI Enable	Discard Intervals	Force HA	Reverse Direction	Zero Now	Auto Zero Mode		Hall Sensor Enable	FW UI Enable
Default: 0x0106															
0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0

- Bit 8: **Hall UI Enable**
  - 0: Hall UI disabled
  - 1: Hall UI enabled
- Bit 7: **Discard Intervals**
  - 0: Keep missed intervals when stationary
  - 1: Discard missed intervals when stationary
- Bit 6: **Force High-accuracy Mode during Freewheeling**
  - 0: Do not force High-accuracy report rate during freewheeling
  - 1: When freewheeling is active, always run at high-accuracy report rate (if auto-power modes are enabled)
- Bit 5: **Reverse Direction**
  - 0: Normal rotation direction
  - 1: Reverse direction of sampled rotation
- Bit 4: **Zero Now**
  - 0: No effect
  - 1: Set current angle to interval 0 (Bit cleared automatically after instruction)
- Bit 2-3: **Auto Zero Mode**
  - 0: Off
  - 1: Stationary
  - 2: Continuous
  - 3: Release
- Bit 1: **Hall Sensor Enable**
  - 0: Hall sensor disabled
  - 1: Hall sensor enabled
- Bit 0: **Freewheel UI Enable**
  - 0: Freewheel UI disabled
  - 1: Freewheel UI enabled

A.14 Hall Fine and Coarse Multipliers (0x80, 0x81)

Table A.14: Hall Fine and Coarse Multipliers

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved		Fine Fractional Divider					Coarse Fractional Multiplier				Coarse Fractional Divider				
Default: 0x05E2															
0	0	0	0	0	1	0	1	1	1	1	0	0	0	1	0

- Bit 9-13: **Fine Fractional Divider**
  - Unsigned 5-bit value
- Bit 5-8: **Coarse Fractional Multiplier**
  - Unsigned 4-bit value
- Bit 0-4: **Coarse Fractional Divider**
  - Unsigned 5-bit value

A.15 Hall Plate Bias 0 (0x82)

Table A.15: Hall Plate Bias 0

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
B1 Bias								A0 Bias							
Default: 0xDBDB															
1	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1

- Bit 8-15: **Plate B1 Bias**
  - Unsigned 8-bit value
- Bit 0-7: **Plate A0 Bias**
  - Unsigned 8-bit value

Hall Plate Bias values should generally not be changed from the default value.

A.16 Hall Plate Bias 1 (0x83)

Table A.16: Hall Plate Bias 1

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
B0 Bias								A1 Bias							
Default: 0xDBDB															
1	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1

- Bit 8-15: **Plate B0 Bias**
  - Unsigned 8-bit value
- Bit 0-7: **Plate A1 Bias**
  - Unsigned 8-bit value

Hall Plate Bias values should generally not be changed from the default value.

A.17 Hall Plate Offset 0 (0x84)

Table A.17: Hall Plate Offset 0

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
B1 Offset								A0 Offset							

- Bit 8-15: **Plate B1 Offset**
  - 8-bit value
- Bit 0-7: **Plate A0 Offset**
  - 8-bit value

A.18 Hall Plate Offset 1 (0x85)

Table A.18: Hall Plate Offset 1

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
B0 Offset								A1 Offset							

- Bit 8-15: **Plate B0 Offset**
  - 8-bit value
- Bit 0-7: **Plate A1 Offset**
  - 8-bit value

A.19 Freewheel Filter Betas (0x90)

Table A.19: Freewheel Filter Betas

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Follow Beta								Decay Beta							
Default: 0x0204															
0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0

- Bit 8-15: **Follow Beta**
  - Unsigned 8-bit value
- Bit 0-7: **Decay Beta**
  - Unsigned 8-bit value

A.20 Freewheel Touch Threshold 0 (0x98)

Table A.20: Freewheel Touch Threshold 0

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Forward Release Threshold								Stop Touch Threshold							
Default: 0x1414															
0	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0

- Bit 8-15: **Forward Release Threshold**
  - Unsigned 8-bit value
- Bit 0-7: **Stop Touch Threshold**
  - Unsigned 8-bit value

A.21 Freewheel Touch Threshold 1 (0x99)

Table A.21: Freewheel Touch Threshold 1

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved								Reverse Release Threshold							
Default: 0x0014															
0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0

- Bit 0-7: **Reverse Release Threshold**
  - Unsigned 8-bit value

A.22 Hall ATI Settings (0xA2)

Table A.22: Hall ATI Settings

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved								Hall ATI Band Fraction							
Default: 0x0203															
0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1

- Bit 0-7: **Hall ATI Band Fraction**
  - Unsigned 8-bit value

A.23 Button Beta 0 (0xB4)

Table A.23: Button Beta 0

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Low Power Beta								Normal Power Beta							
Default: 0x0102															
0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0

- Bit 8-15: **Low Power Beta**
  - Unsigned 8-bit value
- Bit 0-7: **Normal Power Beta**
  - Unsigned 8-bit value

A.24 Button Beta 1 (0xB5)

Table A.24: Button Beta 1

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
LTA Low Power Beta								LTA Normal Power Beta							
Default: 0x0708															
0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0

- Bit 8-15: **LTA Low Power Beta**
  - Unsigned 8-bit value
- Bit 0-7: **LTA Normal Power Beta**
  - Unsigned 8-bit value

A.25 Button Beta 2 (0xB6)

Table A.25: Button Beta 2

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
LTA Low Power Fast Beta								LTA Normal Power Fast Beta							
Default: 0x0304															
0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0

- Bit 8-15: **LTA Low Power Fast Beta**
  - Unsigned 8-bit value
- Bit 0-7: **LTA Normal Power Fast Beta**
  - Unsigned 8-bit value

A.26 Button Reseed Settings (0xB7)

Table A.26: Button Reseed Settings

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
ATI Band Fraction							Reseed Touch	Fast bound							
Default: 0x1005															
0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1

- Bit 9-15: **ATI Band Fraction**
  - Unsigned 7-bit value
- Bit 8: **Reseed Touch**
  - 0: No action taken
  - 1: Reseed touch channel (will reset after instruction)
- Bit 0-7: **Fast Bound**
  - Unsigned 8-bit value

A.27 Button Control 0 (0xC0)

Table A.27: Button Control 0

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved									0.5 V Reference	RF Filter	Reserved	Proj Bias		Max Counts	
Default: 0x7F05															
0	1	1	1	1	1	1	1	0	0	0	0	0	1	0	1

- Bit 6: **0.5 V Reference**
  - 0: 1 V voltage reference
  - 1: 500 mV voltage reference
- Bit 5: **RF Filter**
  - 0: Disable RF Filter
  - 1: Enable RF Filter
- Bit 2-3: **Projected Bias**
  - 0: 2 uA
  - 1: 5 uA
  - 2: 6 uA
  - 3: 10 uA
- Bit 0-1: **Max Counts**
  - 0: 1023
  - 1: 2047
  - 2: 4095
  - 3: 16383

A.28 Button Control 1 (0xC1)

Table A.28: Button Control 1

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CRx3	CRx2	CRx1	CRx0	80 pF Cs	Cap Mode	Inactive VSS	Reserved	Period							
Default: 0x1A10															
0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0

- Bit 12-15: **CRx Select**
  Each bit enables the corresponding Rx pin for the capacitive-sensing channel. For CRx0 to CRx3:
  - 0: Rx disabled
  - 1: Rx enabled
- Bit 11: **80 pF Cs**
  - 0: 40 pF internal reference capacitor (half resolution)
  - 1: 80 pF internal reference capacitor (full resolution)
- Bit 10: **Capacitance Mode**
  - 0: Self-capacitive mode
  - 1: Mutual-capacitive mode
- Bit 9: **Inactive VSS**
  - 0: No action
  - 1: Connect all inactive Cx pins to VSS
- Bit 0-7: **Conversion Frequency Period**
  - The Period value sets the conversion frequency of the capacitive sensor. Given the desired conversion frequency, F_{xfer}, and the system oscillator frequency, F_{OSC}, the Period value can be calculated with:

$$\text{PERIOD} = \frac{1}{2} \times \left(\frac{F_{OSC}}{F_{xfer}} - 3 \right).$$

  - The following table can be used to select appropriate values for the Period value:

Table A.29: Conversion Period Values

Period	Conversion Frequency (F_{xfer})	
	18 MHz F_{OSC}	14 MHz F_{OSC}
1*	3.60 MHz	2.80 MHz
3*	2.00 MHz	1.60 MHz
7	1.05 MHz	820 kHz
9	860 kHz	670 kHz
16	510 kHz	400 kHz
24	350 kHz	280 kHz
34	250 kHz	200 kHz
70	125 kHz	100 kHz

** Please note: The maximum recommended charge transfer frequency* is 1 MHz.

A.29 CTx Select (0xC2)

Table A.30: CTx Select

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved							Tx8	Tx7	Tx6	Tx5	Tx4	Tx3	Tx2	Tx1	Tx0
Default: 0x0001															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

- Bit 0-8: **CTx Selection for Capacitive Channel**
  Each bit enables the corresponding CTx pin for the capacitive-sensing channel. For CTx0 to CTx8:
  - 0: CTx disabled
  - 1: CTx enabled

A.30 Button Settings (0xC3)

Table A.31: Button Settings

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved				Auto Prox Cycles		Reserved			Release UI	Dual Threshold	ATI Mode			Inverse	Button Enable
Default: 0xCF15															
1	1	0	0	1	1	1	1	0	0	0	1	0	1	0	1

- Bit 10-11: **Auto Prox Cycles**
  - This sets the number of low-power measurements performed on the Button channel while in ULP between communication windows.
  - 0: 4
  - 1: 8
  - 2: 16
  - 3: 32
- Bit 6: **Release UI**
  - This bit will allow the reference channel to update during touch, resulting in a negative delta upon release. This setting must be enabled if the Freewheeling feature is used.
  - 0: Release UI disabled
  - 1: Release UI enabled
- Bit 5: **Dual Threshold**
  - This bit will allow touch events to trigger for both positive and negative touch delta values. This setting must be enabled if the Release UI or Freewheeling is used.
  - 0: Dual threshold disabled
  - 1: Dual threshold enabled

- Bit 2-4: **ATI Mode**
  - 0: Disabled
  - 1: Compensation only
  - 2: From compensation divider
  - 3: From fine divider
  - 4: From coarse divider
  - 5: Full
- Bit 1: **Inverse**
  - This bit will affect the direction in which a touch event can be triggered. This bit must be enabled for the mutual-capacitive mode to function.
  - 0: Inverse touch delta disabled
  - 1: Inverse touch delta enabled
- Bit 0: **Button Channel Enabled**
  - 0: Touch button disabled
  - 1: Touch button enabled

A.31 Button Fine and Coarse Multipliers (0xC6)

Table A.32: Button Fine and Coarse Multipliers

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Reserved		Fine Fractional Divider					Coarse Fractional Multiplier				Coarse Fractional Divider				
Default: 0xA048															
1	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0

- Bit 9-13: **Fine Fractional Divider**
  - Unsigned 5-bit value
- Bit 5-8: **Coarse Fractional Multiplier**
  - Unsigned 4-bit value
- Bit 0-4: **Coarse Fractional Divider**
  - Unsigned 5-bit value

A.32 Button Compensation (0xC7)

Table A.33: Button Compensation

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Compensation Divider					Reserved	Compensation Selection									
Default: 0x2DDC															
0	0	1	0	1	1	0	1	1	1	0	1	1	1	0	0

- Bit 11-15: **Compensation Divider**
  - Unsigned 5-bit value
- Bit 0-9: **Compensation Selection**
  - Unsigned 10-bit value

A.33 Prox Threshold (0xD0)

Table A.34: Prox Threshold

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Debounce Exit Prox				Debounce Enter Prox				Threshold Prox							
Default: 0x1214															
0	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0

- Bit 12-15: **Debounce Exit Prox**
  - Unsigned 4-bit value
- Bit 8-11: **Debounce Enter Prox**
  - Unsigned 4-bit value
- Bit 0-7: **Threshold Prox**
  - Unsigned 8-bit value

A.34 Touch Threshold (0xD1)

Table A.35: Touch Threshold

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Touch Hysteresis								Touch Threshold							
Default: 0x3414															
0	0	1	1	0	1	0	0	0	0	0	1	0	1	0	0

- Bit 8-15: **Touch Hysteresis**
  - Unsigned 8-bit value
  - Hysteresis is calculated based on the touch threshold below:

$$\text{Hysteresis} = \frac{\text{Touch Threshold} \times \text{8-bit value}}{256}$$

- Bit 0-7: **Touch Threshold**
  - Unsigned 8-bit value
  - Threshold is calculated as:

$$\text{Touch Threshold} = \frac{\text{LTA} \times \text{8-bit value}}{256}$$

B Revision History

Release	Date	Changes
v1.0	October 2022	› Initial release
v1.1	October 2022	› Added watchdog timer recommendation for halt mode
v1.2	March 2023	› Reduced minimum VDD to 2 V in “Electrical Characteristics”, with footnote disclaimer
v1.3	August 2023	› Added “Implementation and Layout” section › Added CRx and CTx selection bits to memory map › Added default values to all read-write registers in I^2C memory map › Added Hall plate bias registers to I^2C memory map › Removed “Dead-time” and “Frequency Fraction” settings from memory map, as they should be kept default › Corrected conversion frequency calculations for 14 MHz and 18 MHz › Added recommendation to send a Zero command after changing the number of intervals. › Added links to application notes AZD004, AZD125, AZD127 › Added drawings of recommended footprints for QFN20 and WLCSP18 packages. › Added IQS7221E002 order code › Added IQS7221E101 information: • Added “Low Magnetic Field” and “ATI Error” flags • Added “F_{OSC} Selection” bit • Added IQS7221E101ppb to Ordering Code section • Added current consumption tables for IQS7221E101 • Updated electrical specifications to include the 14 MHz F_{OSC} option

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