



# QMI8658C DATASHEET

JANUARY 13, 2021

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# QMI8658C

## Low Noise, Wide Bandwidth 6D Inertial Measurement Unit with Motion Co-Processor and Sensor Fusion

### Features

- Low 15 mdps/ $\sqrt{\text{Hz}}$  gyroscope noise, low-latency, and wide bandwidth for performance applications such robotic vacuums, industrial tilt modules, pedestrian navigation and GNSS augmentation, 5G antenna stabilization, inertial navigation, and large industrial UAVs
- Low Noise 200 $\mu\text{g}/\sqrt{\text{Hz}}$  accelerometer
- Host (slave) interface supports MIPI™ I3C, I<sup>2</sup>C, and 3-wire or 4-wire SPI; auxiliary master I<sup>2</sup>C interface supports an external magnetometer
- Accelerometer and gyroscope sensors feature signal processing paths with digitally programmable data rates and filtering
- Complete inertial measurement unit (IMU) with sensor fusion library with specified orientation accuracy of  $\pm 3^\circ$  pitch and roll,  $\pm 5^\circ$  yaw/heading
- High-performance XKF3™ 6/9-axis sensor fusion with in-run calibration for correction of gyroscope bias drift over-temperature and lifetime
- 3-axis gyroscope and 3-axis accelerometer in a small 2.5 x 3.0 x 0.86 mm 14-pin LGA package
- Integrated Gen 2 AttitudeEngine™ motion co-processor with vector DSP performs sensor fusion at 1 kHz sampling rate, while outputting data to host processor at a lower rate – improving accuracy while reducing processor MIPS, power, and interrupt requirements
- Large 1536-byte FIFO can be used to buffer sensor data to lower system power dissipation
- Motion on demand technology for polling-based synchronization
- Large sensor dynamic ranges from  $\pm 16^\circ/\text{s}$  to  $\pm 2048^\circ/\text{s}$  for gyroscope and  $\pm 2$  g to  $\pm 16$  g for accelerometer
- Low power modes for effective power management
- Digitally programmable sampling rate and filters
- Embedded temperature sensor
- Wide extended operating temperature range (-40°C to 85°C)

### Description

The QMI8658C is a complete 6D MEMS inertial measurement unit (IMU) with 9-axis sensor fusion and specified system level orientation accuracy. When using the QMI8658C in combination with the supplied XKF3 9D-sensor fusion, the system features an accurate  $\pm 3^\circ$  pitch and roll orientation, and a  $\pm 5^\circ$  yaw/heading typical specification.

With tight board-level gyroscope sensitivity of  $\pm 3\%$ , gyroscope noise density of 15 mdps/ $\sqrt{\text{Hz}}$ , and low latency, the QMI8658C is ideal for high performance consumer and for industrial applications.

The QMI8658C incorporates a 3-axis gyroscope and a 3-axis accelerometer. It provides a UI interface (supporting I3C, I<sup>2</sup>C and 3-wire or 4-wire SPI) and a second interface functioning as an I<sup>2</sup>C master for communicating to an external magnetometer.

The QMI8658C incorporates an advanced vector digital signal processor (DSP) motion co-processor called the AttitudeEngine. The AttitudeEngine efficiently encodes high frequency motion at high internal sampling rates, preserving full accuracy across lower-frequency output data rates.

This enables the application to utilize low output data rates (ODRs) or on-demand (host polling) while still acquiring accurate 3D motion data. The AttitudeEngine reduces the data processing and interrupt load on a host processor with no compromises in 3D motion tracking accuracy. The result is very low total system power in combination with high accuracy, which are essential to many portable and battery powered applications.

### Applications

- Toys
- Drones
- E-bikes and scooters
- Motion-based remote controls and air mice

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# 1 General Information

## 1.1 Ordering Information

Table 1. Ordering Information

Part Number	Package	Packing Method
QMI8658C	LGA14	Tape & Reel

## 1.2 Marking Information

ROW	EXAMPLE	CODE/EXPLANATION
1	<b>8658</b>	DDDD – Device code
2	<b>0113</b>	YWLL – Y (Year code), W (1-digit, biweekly code), LL (Lot indication)
3	<b>• DA</b>	CR – C (Assembly location), R (Product revision)

Figure 1. Top Mark

### 1.3 Internal Block Diagram

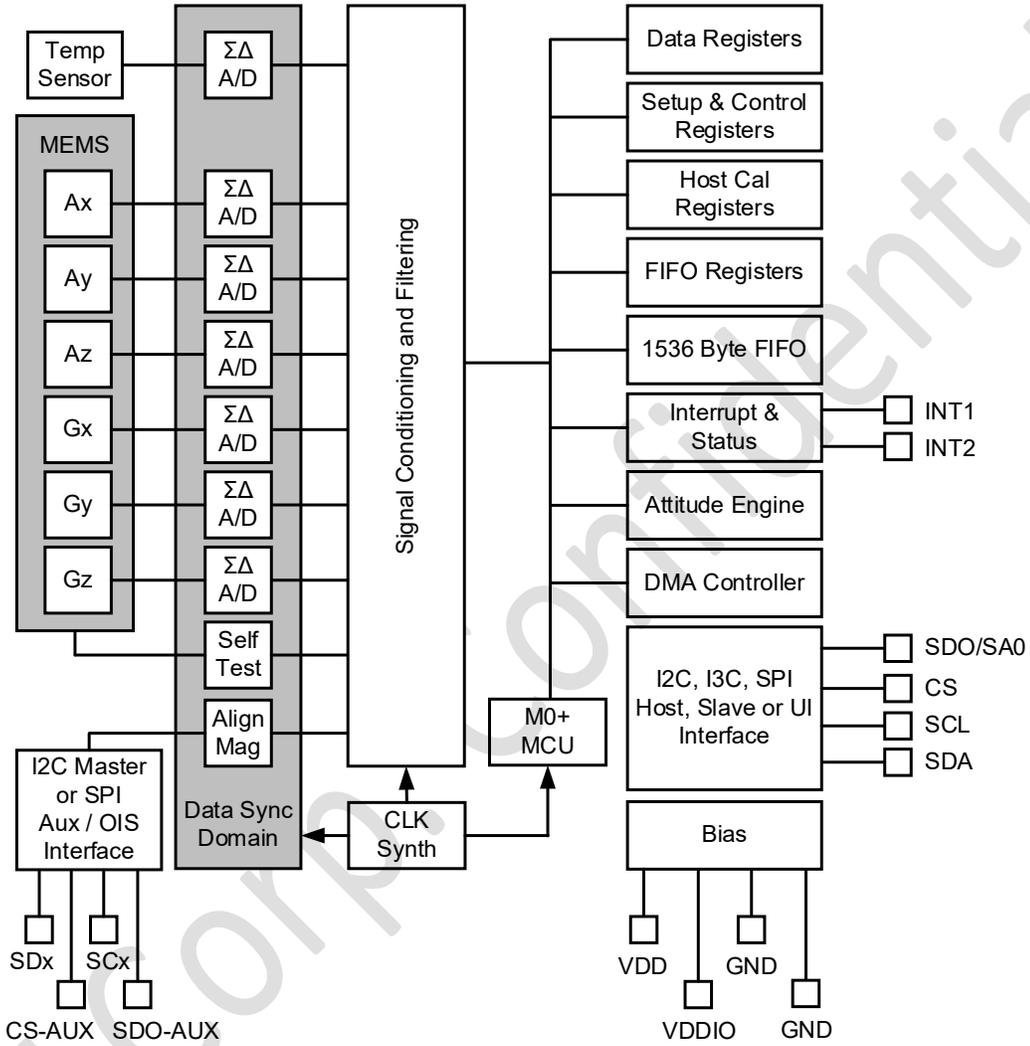


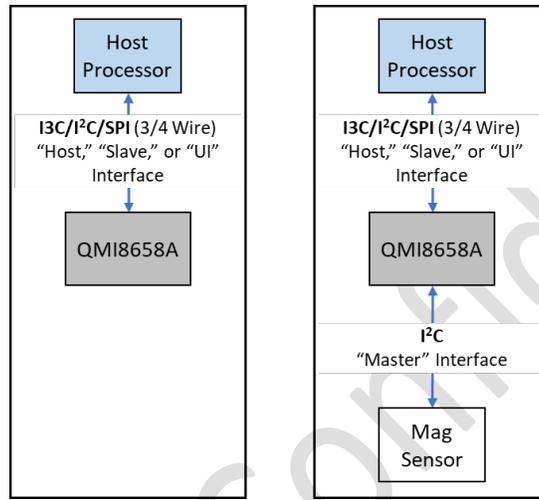
Figure 2. Internal Block Diagram

## 1.4 Interface Operating Modes

The QMI8658C can operate in two different modes, as shown in the Figure below.

**Mode 1: Default mode** of operation. In this mode, the QMI8658C is a slave device to a host processor that communicates to it using one of the following interfaces: I<sup>2</sup>C, I<sup>3</sup>C, and SPI (3-wire or 4-wire modes). This slave relationship to the host is the same for all operating modes. In Mode 1, the secondary interface is not enabled.

**Mode 2: External Sensor mode** of operation. As in Mode 1, the QMI8658C is a slave to the host processor, and communications to it is by one of the following interfaces: I<sup>2</sup>C, I<sup>3</sup>C, and SPI (3-wire or 4-wire modes). However, in Mode 2, the external sensor bus is enabled and the QMI8658C acts as a I<sup>2</sup>C master to an external magnetometer.



Mode 1. Default Mode

Mode 2. Mag Mode

Figure 3. Operating modes

## 1.5 Package & Pin Information

The pinout of the QMI8658C is shown in the figure below. The pin names and functionality are detailed in the table that follows. The pin functionality is dictated by the part's operating mode, as described in the section above.

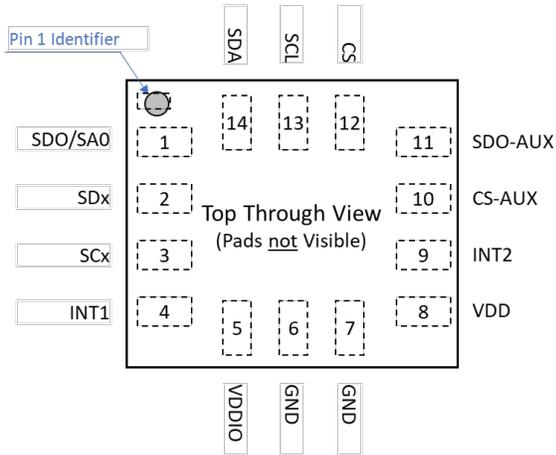


Figure 4. Pins Face Down (Top View)

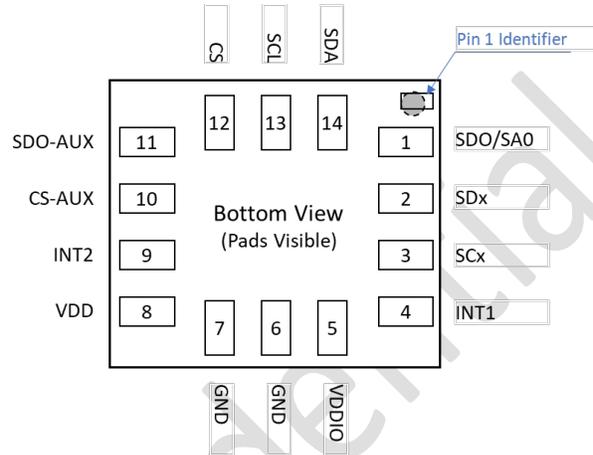


Figure 5. Pins Face Up (Bottom View)

Table 2. Pin Definitions

Pin Number	Type	Pin Name	Mode 1 Function (Default Mode)	Mode 2 Function (External Sensor Mode)
1	O	SDO/SA0 <sup>(1)(3)</sup>	SPI-UI Data Out (SDO) in SPI-UI 4-Wire Mode. I <sup>2</sup> C Slave LSB bit of the device Address (SA0)	
2	IO	SDx	Connect to VDDIO or GND	I <sup>2</sup> C Master Serial Data (MSDA)
3	IO	SCx	Connect to VDDIO or GND	I <sup>2</sup> C Master Serial Clock (MSCL)
4	O	INT1	Programmable Interrupt 1 for I <sup>2</sup> C and SPI	
5	I	VDDIO	Power Supply for IO Pins	
6	I	GND	Ground (0 V supply); is internally No Connect.	
7	I	GND	Ground (0 V supply)	
8	I	VDD	Power supply	
9	O	INT2	Programmable Interrupt 2 (INT2)/ Data Enable (DEN)	Programmable Interrupt 2 (INT2) / Data Enable (DEN). I <sup>2</sup> C Master external Synchronization Signal (MDRDY)
10	IO	RESV-NC	Reserved. No Connect	
11	I	RESV-NC	Reserved. No Connect	
12	I	CS	I <sup>2</sup> C/ I3C /SPI-UI selection Pin. (If 1: I <sup>2</sup> C-UI Mode: I <sup>2</sup> C/I3C communication enabled, SPI idle mode) (If 0: SPI-UI mode: I <sup>2</sup> C/I3C disabled)	
13	IO	SCL	SPI-UI Serial Clock (SPC) <sup>(2)(3)</sup>	
14	IO	SDA	I <sup>2</sup> C/I3C-UI Data (SDA) SPI-UI Data In (SDI) <sup>(2)(3)</sup> in 4 wire Mode SPI-UI Data IO (SDIO) <sup>(2)(3)</sup> in 3 Wire Mode	

**Notes:**

1. This pin has an internal 200 kΩ pull up resistor.
2. In SPI mode (not in I<sup>2</sup>C Mode), there is an internal pull down 200 kΩ resistor.
3. Refer to Section 12 for detailed configuration information.

## 1.6 Recommended External Components

Table 3. Recommended External Components

Component	Description	Parameter	Typical
C <sub>p1</sub>	Capacitor	Capacitance	100 nF
C <sub>p2</sub>	Capacitor	Capacitance	100 nF
R <sub>pu</sub> <sup>(4)</sup>	Resistor	Resistance	10 kΩ

**Note:**

- R<sub>pu</sub> resistors are only needed when the Host Serial Interface is configured for I<sup>2</sup>C (see I<sup>2</sup>C Interface section). They are not needed when the Host Serial Interface is configured for SPI or I3C. If pull-up resistors are used on SCL and SDA, then SPI, I3C and I<sup>2</sup>C Modes are all possible. If a pull-up resistor is used on SA0, an alternate slave address is used for I<sup>2</sup>C. SPI and I3C modes will be unaltered with the use of pull-up resistors for I<sup>2</sup>C. Additionally, a suitable pull up resistance (R<sub>pu</sub>) value should be selected, accounting for the tradeoff between current consumption and rise time.

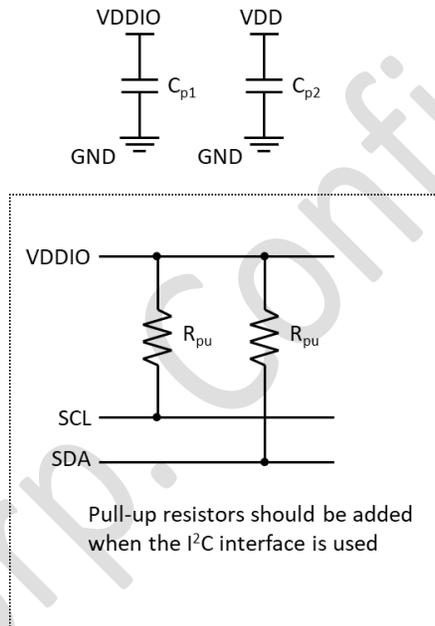


Figure 6. Typical Electrical Connections

## 2 QMI8658C Architecture

QMI8658C is a smart sensor that combines a high-performance IMU with a powerful Single Instruction Multiple Data (SIMD) based Vector DSP motion co-processor referred to as the AttitudeEngine™ (AE).

Included sensor fusion software (XKF3) allows the device to achieve orientation accuracies of  $\pm 3^\circ$  for pitch and roll and  $\pm 5^\circ$  for yaw/heading.

The QMI8658C includes a microcontroller for data scheduling, combined with Direct Memory Access (DMA) in order to allow efficient data shuttling on the chip. Multi-channel data is easily processed at rates up to 1 kHz.

An internal block diagram is shown in Figure 2. The MEMS elements are amplified and converted by  $\Sigma\Delta$  A/D converters, which are synchronized to a common clock so that all the motion measurements of acceleration, angular rate and magnetic heading are sampled at the same time minimizing any skew between channels. The data is then sent to a signal processing chain that accomplishes decimation, filtering, and calibration.

Once the data has been processed, it can be sent to the host processor depending on additional configuration settings, such as enabling the FIFO or using the AttitudeEngine.

### 2.1 AttitudeEngine Mode Overview

Brief descriptions of the major functions of the AttitudeEngine are discussed below. Note that the AttitudeEngine may be enabled or disabled and configured using the CTRL6 register.

- **Calibration:** The QMI8658C applies continuous on-chip calibration of all the sensors (accelerometer, gyroscope, and magnetometer) including scale, offset, and temperature calibration. When used in conjunction with a sensor fusion filter (such as the XKF3) running on the host processor, estimated sensor errors can be updated in-use, allowing sensor calibration to be performed in the background without any host intervention. This offloads computationally expensive per-sample re-calibration from the host processor to the QMI8658C.
- **Sample Synchronization:** The QMI8658C automatically provides highly synchronous output between the various IMU accelerometer and gyroscope channels by using fully parallel  $\Sigma\Delta$ -converters. The QMI8658C also provides time synchronization of data between the IMU and the external magnetometer.
- **Motion Encoder:** The on-chip motion encoder performs 32-bit high-speed dead reckoning

calculations at 1 kHz data rates allowing accurate capture of high frequency and coning effects. Orientation and velocity increments are calculated with full coning and sculling compensation and the magnetic field vector from the external magnetometer is rotated to the sensor frame of reference. This allows the lossless encoding (compression) of 6D motion to a low output data rate, while maintaining the accuracy provided by the 1 kHz input and data processing rate. Motion data encoded by the AttitudeEngine is available at a user programmable data rate (1 Hz to 64 Hz). The orientation and velocity increments from the AttitudeEngine are suitable for any 3D motion tracking application (orientation, velocity, and position) and may be further fused by the user with information from other sources such as a GNSS receiver or barometer in an optimal estimator.

- **Motion on Demand (MoD):** The QMI8658C allows the host to access encoded motion data asynchronously (polling) and on demand. The motion data in the AttitudeEngine (AE) mode remains accurate even at very low output data rates. This allows easy integration and synchronization with other sensors for state-of-the-art applications such as rolling shutter camera stabilization, optical sensors software de-blurring, GNSS integration and augmented or virtual reality.

### 2.2 Advantages of the Attitude Engine Approach

The advantages of the AttitudeEngine (AE) approach over the traditional sensor approach are briefly discussed below.

- **Low-Power Architecture:** Dead reckoning calculations are performed with the AE vector DSP that is designed to perform essential calculations while achieving high accuracy and low power simultaneously. The AE approach enables a typical interrupt rate reduction to the host processor of 10x and can be up to 100x for some applications. This significantly enhances the operational life of battery powered devices without any compromises in 3D motion tracking accuracy.
- **High Performance:** The motion encoder and sample synchronizer enable highly accurate strap down integration that can be fully compensated for coning and sculling artifacts.

### 2.3 9D Sensor Fusion and Auto-Calibration using XKF3

XKF3 is a sensor fusion algorithm, based on Extended Kalman Filter theory that fuses 3D inertial sensor data (orientation and velocity increments) and 3D magnetometer, also known as '9D', data to optimally estimate 3D orientation with respect to an Earth fixed frame.

A license to use XKF3 in a CMSIS compliant library form for Cortex M0+, M3, M4, M4F, for commercial purposes is provided with certain QST evaluation kits incorporating the QMI8658C.

A restricted-use license for use of XKF3 for commercial purposes is also granted for certain applications when XKF3 is used with the QMI8xxx series of IMUs, such as the QMI8658C/B/C family and the QMI8610.

#### XKF3 Features:

- Continuous Sensor Auto Calibration, No User Interaction Required
- High Accuracy, Real-Time, Low-Latency Optimal estimate of 3D Orientation, up to 1 kHz output data rate
- Ultra-low system power for 3D Orientation enabled by AttitudeEngine between 1 to 64 Hz output data rate without any degradation in accuracy
- Best-in-Class Immunity to Magnetic Distortions
- Best-in-Class Immunity to Transient Accelerations
- Flexible use Scenarios, North Referenced, Unreferenced
- Extensive Status Reporting for Smooth Integration in Applications
- Optimized Library for Popular Microcontrollers

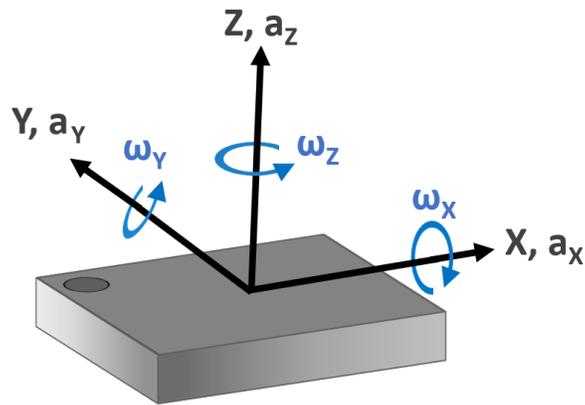


Figure 7. Chip Orientation Coordinate System

## 2.4 Frames of Reference and Conventions for Using QMI8658C

The QMI8658C uses a right-handed coordinate system as the basis for the sensor frame of reference. Acceleration ( $a_x, a_y, a_z$ ) are given with respect to the X-Y-Z co-ordinate system shown above. Increasing accelerations along the positive X-Y-Z axes are considered positive. Angular Rate ( $\omega_x, \omega_y, \omega_z$ ) in the

counterclockwise direction around the respective axis are considered positive. Magnetic fields ( $m_x, m_y, m_z$ ) can be configured to be expressed in the sensor X-Y-Z coordinates as well. Care must be taken to make sure that QMI8658C and the magnetic sensor of choice are mounted on the board so that the coordinate systems of the two sensors are substantially parallel. Figure 7 shows the various frames of reference and conventions for using the QMI8658C.

### 3 System, Electrical and Electro-Mechanical Characteristics

#### 3.1 Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions. Stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

Table 4. Absolute Maximum Ratings

Symbol	Parameter	Min.	Max.	Unit
T <sub>STG</sub>	Storage Temperature	-40	+125	°C
T <sub>Pmax</sub>	Lead Soldering Temperature, 10 Seconds		+260	°C
VDD	Supply Voltage	-0.3	3.6	V
VDDIO	I/O Pins Supply Voltage	-0.3	3.6	V
S <sub>g</sub> <sup>(5)</sup>	Acceleration g for 0.2 ms (Un-powered)		10,000	g
ESD <sup>(6)</sup>	Electrostatic Discharge Protection Level	Human Body Model per JES001-2014	±2000	V
		Charged Device Model per JESD22-C101	±500	

**Notes:**

- 5.  $\Delta$  This is a mechanical shock (g) sensitive device. Proper handling is required to prevent damage to the part.
- 6.  $\nearrow$  This is an ESD-sensitive device. Proper handling is required to prevent damage to the part.

#### 3.2 Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for device operation. Recommended operating conditions are specified to ensure optimal performance. QST does not recommend exceeding them or designing to Absolute Maximum Ratings.

Table 5. Recommended Operating Conditions

Symbol	Parameter	Min	Typ	Max	Unit
VDD	Supply Voltage	1.71	1.8	3.6	V
VDDIO	I/O Pins Supply Voltage	1.71	1.8	3.6	V
V <sub>IL</sub>	Digital Low Level Input Voltage			0.3 *VDDIO	V
V <sub>IH</sub>	Digital High Level Input Voltage	0.7 *VDDIO			V
V <sub>OL</sub>	Digital Low Level Output Voltage			0.1 *VDDIO	V
V <sub>OH</sub>	Digital High Level Output Voltage	0.9 *VDDIO			V

### 3.3 System Level Specifications

System level specifications are provided to give guidance on the system performance in a recommended and typical configuration. The recommended system configuration is the QMI8658C and optionally a supported 3D magnetometer used with a supported host processor, running the XKF3 9D-sensor fusion and having executed and stored the result of the “Board Level Calibration” routine. The system performance specifications assume that good engineering practices

for the placement conditions of the QMI8658C and 3D magnetometer are considered. For example, do not place the QMI8658C where strong vibrations may occur or could be amplified; do not place the 3D magnetometer where magnetic fields other than the Earth magnetic field may be measured. Typical numbers are provided below unless otherwise noted.

Table 6. System Level 3D Orientation Accuracy Specifications

Subsystem	Parameter	Typical	Unit	Comments
QMI8658C+XKF3 Quaternion	Roll	±3	deg	Requires use of XKF3 software library on host processor.
	Pitch	±3	deg	Requires use of XKF3 software library on host processor.
	Yaw (Heading) Referenced to North	±5	deg	Requires use of XKF3 software library on host processor, using magnetometer, in a homogenous Earth magnetic field.
	Yaw (Heading) Unreferenced	5-25	deg/h	From Allan Variance bias instability. Does not require a magnetometer. (See specification above for use with magnetometer.) Fully immune to magnetic distortions.
QMI8658C+XKF3 Quaternion	Output Data Rate	1-1000	Hz	To benefit from the power saving using the AttitudeEngine, use a max ODR of 64 Hz.

### 3.4 Electro-Mechanical Specifications

VDD = VDDIO = 1.8 V, T = 25°C unless otherwise noted.

Table 7. Accelerometer Electro-Mechanical Specifications

Subsystem	Parameter	Typical		Unit	Comments	
Accelerometer	Noise Density (@ 32Hz)	200		μg/√Hz	High-Resolution Mode	
	Sensitivity Scale Factor	Scale Setting	Sensitivity		LSB/g	16-Bit Output
		±2 g	16,384			
		±4 g	8,192			
		±8 g	4,096			
		±16 g	2,048			
	Cross-Axis Sensitivity	±2		%		
	Temperature Coefficient of Offset (TCO)	±0.5		mg/°C	Over-Temperature Range of -40°C to 85°C, at Board Level	
	Temperature Coefficient of Sensitivity (TCS)	±0.04		%/°C		
	Initial Offset Tolerance	±100		mg	Board Level	
Initial Sensitivity Tolerance	±6		%	Board Level		
Non-Linearity	±0.75		%	Best Fit Line		
	System Turn On Time <sup>(7)</sup>	1.75		s	From Software Reset, No Power, or Power Down to Power-on Default state = t0 in Figure 8	
	Accel Turn On Time	3 ms + 3/ODR		ms	Accel Turn on from Power-On Default state or from Low Power state = t2 + t5 in Figure 8.	

**Note:**

7. System Turn On Time starts once VDDIO and VDD are within 1% of Final Value.

Table 8. Gyroscope Electro-Mechanical Specifications

Subsystem	Parameter	Typical		Unit	Comments
		Scale Setting	Sensitivity		
Gyroscope	Sensitivity	±16 dps	2048	LSB/dps	16-Bit Output
		±32 dps	1024		
		±64 dps	512		
		±128 dps	256		
		±256 dps	128		
		±512 dps	64		
		±1024 dps	32		
		±2048 dps	16		
	Natural Frequency	24.5		kHz	
	Noise Density (@ 32Hz)	15		mdps/√Hz	High-Resolution Mode
	Non-Linearity	0.2		%	
	Cross-Axis Sensitivity	±2		%	
	g-Sensitivity	±0.1		dps/g	
	System Turn On Time <sup>(8)</sup>	1.75		s	From Software Reset, No Power, or Power Down to Power-on Default state = t0 in Figure 8
Gyro Turn On Time	60 ms + 3/ODR		ms	from Power-On Default = t18	
Temperature Coefficient of Offset (TCO)	±0.05		dps/°C	Over-Temperature Range of -40°C to 85°C	
Temperature Coefficient of Sensitivity (TCS)	±0.05		%/°C	Over-Temperature Range of -40°C to 85°C	
Initial Offset Tolerance	±10		dps	Board Level	
Initial Sensitivity Tolerance	±3		%	Board Level	

**Note:**

8. System Turn On Time starts once VDDIO and VDD are within 1% of Final Value

Table 9. Magnetometer and AttitudeEngine Range and Scale

Subsystem	Parameter	Typical		Unit	Comments
		Scale Setting	Sensitivity		
Typical Sensor Mode	Magnetometer Sensitivity Scale Factor	Depends on magnetometer	Depends on magnetometer	LSB/gauss	16 Bit Output
AE Mode	Magnetometer Sensitivity Scale Factor	Depends on magnetometer	Depends on magnetometer	LSB/gauss	
	Orientation Increment (quaternion) Sensitivity Scale Factor	±1	16,384	LSB/unit	
	Velocity Increment Sensitivity Scale Factor	±32	1,024	LSB/ms	

### 3.5 Accelerometer Programmable Characteristics

VDD = VDDIO = 1.8 V, T = 25°C unless otherwise noted. Typical numbers are provided below unless otherwise noted. All frequencies are ±5% and are synchronized to the gyroscope oscillator (“drive”) frequency.

Table 10. Accelerometer Noise Density

Mode	High-Resolution										Low-Power			Unit
ODR	8000 <sup>(9)</sup>	4000 <sup>(9)</sup>	2000 <sup>(9)</sup>	1000	500	250	125	62.5	31.25	128	21	11	3	Hz
Typical Noise Density	100	100	100	100	100	100	100	100	100	125	180	285	700	μg/√Hz

Note:

9. Available only when both gyroscope and accelerometer are enabled (6DOF mode).

Table 11. Accelerometer Filter Characteristics<sup>(10)</sup>

Mode	High-Resolution										Low-Power			Unit
ODR	8000 <sup>(11)</sup>	4000 <sup>(11)</sup>	2000 <sup>(11)</sup>	1000	500	250	125	62.5	31.25	128	21	11	3	Hz
Bandwidth (Default)	4000	2000	1000	500	250	125	62.5	31.3	15.6	64	10.5	5.5	1.5	
Bandwidth with Low-Pass Filter Enabled Mode 00 (2.62% of ODR)	209.6	104.8	52.4	26.2	13.1	6.6	3.3	1.6	0.8	3.4	0.6	0.3	0.1	
Bandwidth with Low-Pass Filter Enabled Mode 01 (3.59% of ODR)	287.2	143.6	71.8	35.9	18	9	4.5	2.2	1.1	4.6	0.8	0.4	0.1	
Bandwidth with Low-Pass Filter Enabled Mode 10 (5.32% of ODR)	425.6	212.8	106.4	53.2	26.6	13.3	6.7	3.3	1.7	6.8	1.1	0.6	0.2	
Bandwidth with Low-Pass Filter Enabled Mode 11 (14.0% of ODR)	1120	560	280	140	70	35	17.5	8.8	4.4	17.9	2.9	1.5	0.4	

Note:

10. All frequencies are ±5% and are synchronized to the gyroscope oscillator (“drive”) frequency.

11. Available only when both gyroscope and accelerometer are enabled (6DOF mode).

### 3.6 Gyroscope Programmable Characteristics

VDD = VDDIO = 1.8 V, T = 25°C, and represent typical numbers unless otherwise noted. All frequencies are ±5% and are synchronized to the gyroscope oscillator (“drive”) frequency.

Table 12. Gyroscope Filter Characteristics

Mode	High-Resolution									Unit
	8000	4000	2000	1000	500	250	125	62.5	31.25	
<b>ODR</b>	8000	4000	2000	1000	500	250	125	62.5	31.25	Hz
<b>Bandwidth (Default)</b>	4000	2000	1000	500	250	125	62.5	31.3	15.6	
<b>Bandwidth with Low-Pass Filter Enabled Mode 00 (2.62% of ODR)</b>	209.6	104.8	52.4	26.2	13.1	6.6	3.3	1.6	0.8	
<b>Bandwidth with Low-Pass Filter Enabled Mode 01 (3.59% of ODR)</b>	287.2	143.6	71.8	35.9	18	9	4.5	2.2	1.1	
<b>Bandwidth with Low-Pass Filter Enabled Mode 10 (5.32% of ODR)</b>	425.6	212.8	106.4	53.2	26.6	13.3	6.7	3.3	1.7	
<b>Bandwidth with Low-Pass Filter Enabled Mode 11 (14.0% of ODR)</b>	1120	560	280	140	70	35	17.5	8.8	4.4	

### 3.7 Electrical Characteristics

VDD = VDDIO = 1.8 V, T = 25°C unless otherwise noted.

Table 13. Electrical Subsystem Characteristics

Symbol	Parameter	Min.	Typ.	Max.	Unit
f <sub>SPC</sub>	Host SPI Interface Speed		15		MHz
f <sub>SCL</sub>	Host I <sup>2</sup> C Interface Speed	Standard Mode	100		kHz
		Fast Mode	400		
f <sub>SCL2</sub>	Master I <sup>2</sup> C Interface Speed <sup>(12)</sup>	Standard Mode	25		kHz
		Fast Mode	300		
f <sub>SCL3</sub>	Host I3C Interface Speed	Standard Data Rate (SDR)	12.5		MHz

**Note:**

12. When only accelerometer is enabled, I<sup>2</sup>C master operates at 25 kHz. When gyroscope is enabled, I<sup>2</sup>C master operates at 300 kHz.

#### 3.7.1 Current Consumption

VDD = VDDIO = 1.8 V, T = 25°C unless otherwise noted. IDD Current refers to the current flowing into the VDD pin. Typical numbers are provided below.

Table 14. Current Consumption for Accelerometer Only Typical Sensor Mode (Gyroscope Disabled)

Mode		High-Resolution						Low-Power				Unit
ODR		1000	500	250	125	62.5	31.25	128	21	11	3	Hz
Typical Overall IDD Current	Filters Disabled (aLPF=0)	182	155	142	134	133	132	55	42	35	30	μA
	Filters Enabled (aLPF=1)	182	155	142	134	133	132	55	42	35	30	

Table 15. Current Consumption for Gyroscope Only Typical Sensor Mode (Accelerometer Disabled)

Mode		High-Resolution									Unit
ODR		8000	4000	2000	1000	500	250	125	62.5	31.25	Hz
Typical Overall IDD Current	Filters Disabled (gLPF=0)	908	861	748	689	659	656	654	653	651	μA
	Filters Enabled (gLPF=1)	916	863	748	689	659	656	654	653	651	

Table 16. Current Consumption for 6DOF Typical Sensor Mode (Accelerometer and Gyroscope Enabled). VDD = VDDIO = 1.8V

Mode		High-Resolution									Unit
ODR		8000	4000	2000	1000	500	250	125	62.5	31.25	Hz
Typical Overall IDD Current	Filters Disabled (aLPF=0; gLPF=0)	1004	956	843	786	757	754	752	751	750	μA
	Filters Enabled (aLPF=1; gLPF=1)	1031	970	850	789	758	756	753	751	750	

Table 17. Current Consumption for 6DOF Attitude Engine Mode (without Magnetometer). VDD = VDDIO = 1.8V

Mode									Unit
ODR Setting		1	2	4	8	16	32	64	Hz
Typical Overall IDD Current	Filters Disabled (aLPF=0; gLPF=0)	783	783	783	783	783	783	783	μA
	Filters Enabled (aLPF=1; gLPF=1)	787	787	787	787	787	787	787	

Table 18. Current Consumption for 9DOF Attitude Engine Mode (with Magnetometer). VDD = VDDIO = 1.8V

Mode									Unit
ODR		1	2	4	8	16	32	64	Hz
Typical Overall IDD Current	With Magnetometer at 31.25 Hz	tbd	μA						

### 3.8 Temperature Sensor

The QMI8658C is equipped with an internal 16-bit embedded temperature sensor that is automatically turned on by default whenever the accelerometer or gyroscope is enabled. The temperature sensor is used internally to correct the temperature dependency of calibration parameters of the accelerometer and gyroscope. The temperature compensation is optimal in the range of -40°C to 85°C with a resolution of 0.0625°C (1/16 °C) or inversely, 16 LSB/°C.

The QMI8658C outputs the internal chip temperature that the HOST can read. The output is 16 bits, with a (1/256)°C per LSB resolution. To read the temperature, the HOST needs to access the TEMP register (see TEMP\_L and TEMP\_H in Data Output Registers in Table 20). The HOST should synchronize to the interrupt, INT2, signal to get valid temperature readings.

Table 19. Temperature Sensor Specifications

Subsystem	Parameter	Typical	Unit
Digital Temperature Sensor	Range	-40 to +85	°C
	Internal Resolution	16	Bits
	Internal Sensitivity	256	LSB/°C
	Output Register Width	16	Bits
	Output Sensitivity	256	LSB/°C
	Refresh Rate	8	Hz

## 4 Register Map Overview

The QMI8658C UI registers enable programming and control of the inertial measurement unit and associated on-chip signal processing. These registers are accessed through the UI interface – either SPI (4 wires or 3 wires) I3C, or I<sup>2</sup>C.

### 4.1 UI Register Map Overview

UI register map may be classified into the following register categories:

- General Purpose Registers
- Setup and Control Registers: control various aspects of the IMU.
- Host Controlled Calibration Registers: control and configure various aspects of the IMU via the host command interface called CTRL9
- Count Register for time stamping the sensor samples
- FIFO Registers: to set up the FIFO and detect data availability and over-run.
- Table 20 for UI Interface: contain all data for 9D sensors to be accessed from the UI interface – either I<sup>2</sup>C or SPI.

Table 20. UI Register Overview

Name	Type	Register Address			Default	Comment
		Dec	Hex	Binary	Binary	
<b>General Purpose Registers</b>						
WHO_AM_I	r	0	00	00000000	0000101	Device Identifier
REVISION_ID	r	1	01	00000001	01101000	Device Revision ID
<b>Setup and Control Registers</b>						
CTRL1	rw	2	02	00000010	00100000	SPI Interface and Sensor Enable
CTRL2	rw	3	03	00000011	00000000	Accelerometer: Output Data Rate, Full Scale, Self Test
CTRL3	rw	4	04	00000100	00000000	Gyroscope: Output Data Rate, Full Scale, Self Test
CTRL4	rw	5	05	00000101	00000000	Magnetometer Settings: Output Data Rate, and Device Selection
CTRL5	rw	6	06	00000110	00000000	Low pass filter setting.
CTRL6	rw	7	07	00000111	00000000	AttitudeEngine™ Settings: Output Data Rate, Motion on Demand
CTRL7	rw	8	08	00001000	00000000	Enable Sensors
CTRL8	rw	9	09	00001001	00000000	Reserved: Not Used
CTRL9	rw	10	0A	00001010	00000000	Host Commands
<b>Host Controlled Calibration Registers (See CTRL9, Usage is Optional)</b>						
CAL1_L	rw	11	0B	00001011	00000000	Calibration Register
CAL1_H	rw	12	0C	00001100	00000000	CAL1_L – lower 8 bits. CAL1_H – upper 8 bits.

CAL2_L	rw	13	0D	00001101	00000000	Calibration Register
CAL2_H	rw	14	0E	00001110	00000000	CAL2_L – lower 8 bits. CAL2_H – upper 8 bits.
CAL3_L	rw	15	0F	00001111	00000000	Calibration Register
CAL3_H	rw	16	10	00010000	00000000	CAL3_L – lower 8 bits. CAL3_H – upper 8 bits.
CAL4_L	rw	17	11	00010001	00000000	Calibration Register
CAL4_H	rw	18	12	00010010	00000000	CAL4_L – lower 8 bits. CAL4_H – upper 8 bits.
<b>FIFO Registers</b>						
FIFO_WTM_T H	rw	19	13	00010011	00000000	FIFO watermark level, in ODRs
FIFO_CTRL	rw	20	14	00010100	00000000	FIFO Setup
FIFO_SMPL_C NT	r	21	15	00010101	00000000	FIFO sample count LSBs
FIFO_STATUS	r	22	16	00010110	00000000	FIFO Status
FIFO_DATA	r	23	17	00010111	00000000	FIFO Data
<b>Status Registers</b>						
I2CM_STATUS	r	44	2C	00101100	00000000	I2C Master Status.
STATUSINT	r	45	2D	00101101	00000000	Sensor Data Availability with the Locking mechanism.
STATUS0	r	46	2E	00101110	00000000	Output Data Over Run and Data Availability.
STATUS1	r	47	2F	00101111	00000000	Miscellaneous Status: Wake on Motion, CmdDone (CTRL9 protocol bit).
<b>Timestamp Register</b>						
TIMESTAMP_ LOW	r	48	30	00110000	00000000	Sample Time Stamp TIMESTAMP_LOW – lower 8 bits. TIMESTAMP_MID – middle 8 bits. TIMESTAMP_HIGH – upper 8 bits
TIMESTAMP_ MID	r	49	31	00110001	00000000	
TIMESTAMP_ HIGH	r	50	32	00110010	00000000	
<b>Data Output Registers (16 bits 2's Complement Except Self-Test Sensor Data, AE-CLIP and AE_OVFLOW)</b>						
TEMP_L	r	51	33	00110011	00000000	Temperature Output Data
TEMP_H	r	52	34	00110100	00000000	TEMP_L – lower 8 bits. TEMP_H – upper 8 bits
AX_L	r	53	35	00110101	00000000	X-axis Acceleration
AX_H	r	54	36	00110110	00000000	AX_L – lower 8 bits. AX_H – upper 8 bits
AY_L	r	55	37	00110111	00000000	Y-axis Acceleration
AY_H	r	56	38	00111000	00000000	AY_L – lower 8 bits. AY_H – upper 8 bits
AZ_L	r	57	39	00111001	00000000	Z-axis Acceleration
AZ_H	r	58	3A	00111010	00000000	AZ_L – lower 8 bits. AZ_H – upper 8 bits
GX_L	r	59	3B	00111011	00000000	X-axis Angular Rate
GX_H	r	60	3C	00111100	00000000	GX_L – lower 8 bits. GX_H – upper 8 bits
GY_L	r	61	3D	00111101	00000000	Y-axis Angular Rate
GY_H	r	62	3E	00111110	00000000	GY_L – lower 8 bits. GY_H – upper 8 bits
GZ_L	r	63	3F	00111111	00000000	Z-axis Angular Rate
GZ_H	r	64	40	01000000	00000000	GZ_L – lower 8 bits. GZ_H – upper 8 bits
MX_L	r	65	41	01000001	00000000	X-axis Magnetic Field
MX_H	r	66	42	01000010	00000000	MX_L – lower 8 bits. MX_H – upper 8 bits
MY_L	r	67	43	01000011	00000000	Y-axis Magnetic Field
MY_H	r	68	44	01000100	00000000	MY_L – lower 8 bits. MY_H – upper 8 bits

MZ_L	r	69	45	01000101	00000000	Z-axis Magnetic Field
MZ_H	r	70	46	01000110	00000000	MZ_L – lower 8 bits. MZ_H – upper 8 bits
dQW_L	r	73	49	01001001	00000000	Quaternion Increment dQW
dQW_H	r	74	4A	01001010	00000000	dQW_L – lower 8 bits. dQW_H – upper 8 bits
dQX_L	r	75	4B	01001011	00000000	Quaternion Increment dQX
dQX_H	r	76	4C	01001100	00000000	dQX_L – lower 8 bits. dQX_H – upper 8 bits
dQY_L	r	77	4D	01001101	00000000	Quaternion Increment dQY
dQY_H	r	78	4E	01001110	00000000	dQY_L – lower 8 bits. dQY_H – upper 8 bits
dQZ_L	r	79	4F	01001111	00000000	Quaternion Increment dQZ
dQZ_H	r	80	50	01010000	00000000	dQZ_L – lower 8 bits. dQZ_H – upper 8 bits
dVX_L	r	81	51	01010001	00000000	Velocity Increment along X-axis
dVX_H	r	82	52	01010010	00000000	dVX_L – lower 8 bits. dVX_H – upper 8 bits
dVY_L	r	83	53	01010011	00000000	Velocity Increment along Y-axis
dVY_H	r	84	54	01010100	00000000	dVY_L – lower 8 bits. dVY_H – upper 8 bits
dVZ_L	r	85	55	01010101	00000000	Velocity Increment along Z-axis
dVZ_H	r	86	56	01010110	00000000	dVZ_L – lower 8 bits. dVZ_H – upper 8 bits
AE_REG1	r	87	57	01010111	00000000	AttitudeEngine Register 1
AE_REG2	r	88	58	01011000	00000000	AttitudeEngine Register 2
<b>Reset Register</b>						
RESET	w	196	60	01100000	00000000	Soft Reset Register

## 5 UI Sensor Configuration Settings and Output Data

### 5.1 Typical Sensor Mode Configuration and Output Data

In Typical Sensor Mode, QMI8658C outputs raw sensor values. The sensors are configured and read using the registers described below. The accelerometer, gyroscope and magnetometer can be independently configured. Table 21 summarizes these pertinent registers.

Table 21. Typical Sensor Mode Configuration and Output Data

Typical Sensor Configuration and Output Data			
Description	Registers	Unit	Comments
Sensor Enable, SPI 3 or 4 Wire	CTRL1		Control power states, configure SPI communications
Enable Sensor	CTRL7		Individually Enable/Disable the AttitudeEngine, Accelerometer, Gyroscope and Magnetometer Using sEN, aEN, gEN, and mENbits, respectively.
Configure Accelerometer, Enable Self Test	CTRL2		Configure Full Scale and Output Data Rate; Enable Self Test
Configure Gyroscope, Enable Self Test	CTRL3		Configure Full Scale and Output Data Rate; Enable Self Test
Configure Magnetometer	CTRL4		Configure Output Data Rate and Choose Device
Sensor Filters	CTRL5		Configure and Enable/Disable Low Pass Filters
Status	STATUSINT STATUS0, STATUS1		Data Availability, FIFO Ready to be Read, CTRL9 Protocol Bit
Time Stamp	TIMESTAMP[ H,M,L]		Sample Time Stamp (Circular Register 0 – 0xFFFFF)
Acceleration	A[X,Y,Z]_[H,L]	g	In Sensor Frame of Reference, Right-handed Coordinate System
Angular Rate	G[X,Y,Z]_[H,L]	dps	In Sensor Frame of Reference, Right-handed Coordinate System
Magnetic Field	M[X,Y,Z]_[H,L]	gauss	In Sensor Frame of Reference, Right-handed Coordinate System
Temperature	TEMP_[H,L]	° C	Temperature of the Sensor
FIFO Based Output	FIFO_DATA		1 Byte FIFO Data Outputs

## 5.2 AttitudeEngine (AE) Mode Configuration and Output Data

In AE Mode, the QMI8658C outputs orientation (quaternion) and velocity increments.

Orientation increments are expressed in unit quaternion format.  $dQ = [QW, QX, QY, QZ]$  where QW is the scalar component of the quaternion increment and QX, QY and QZ are the (imaginary) vector components of the unit quaternion. Velocity increments are expressed in vector format  $dV = [VX, VY, VZ]$ .

Table 22 summarizes the operation of the AttitudeEngine mode.

Table 22. AttitudeEngine Mode Configuration and Output Registers

AttitudeEngine Mode			
Configuration	Registers	Unit	Comments
Sensor Enable, SPI 3 or 4 Wire	CTRL1		Control power states, SPI communications
Enable AttitudeEngine	CTRL7		Enable the AttitudeEngine (CTRL7, sEN =1, aEN=1, gEN=1, optionally mEN=1 if external magnetometer is available)
Configure	CTRL6		AttitudeEngine Output Data Rate and Motion on Demand
Configure Accelerometer, Enable Self Test	CTRL2		Configure Full Scale; Enable Self Test
Configure Gyroscope, Enable Self Test	CTRL3		Configure Full Scale; Enable Self Test
Configure Magnetometer	CTRL4		Configure Output Data Rate and choose device
Sensor Filters	CTRL5		Configure and Enable/Disable Low Pass Filters
Quaternion Increment	dQ[W,X,Y,Z]_[H,L]		Unit Quaternion format in sensor frame
Velocity Increment	dV[X,Y,Z]_[H,L]	ms <sup>-1</sup>	Rotation compensated velocity increment (based on specific force), rotated to sensor frame of reference
Magnetic Field	M[X,Y,Z]_[H,L]	gauss	Rotation compensated magnetic field (rotated to sensor frame of reference)
Status	STATUSINT STATUS0, STATUS1		Data Availability, Wake on Motion detected
Bias Update, Clipping, Overflow	AE_CLIP, AE_OVERFLOW		Magnetometer and Gyroscope bias update acknowledgement, Sensor clipping acknowledgement, Velocity increment overflow
Temperature	TEMP_[H,L]	° C	Temperature of the sensor

## 5.3 General Purpose Register

Table 23. General Purpose Register Description

Register Name			
WHO_AM_I		Register Address: 0 (0x00)	
Bits	Name	Default	Description
7:0	WHO_AM_I	0x05	Device identifier 0x05 - to identify the device is a QST sensor
7:0	REVISION_ID	0x79	Device Revision ID

## 5.4 Configuration Registers

This section describes the various operating modes and register configurations of the QMI8658C.

Table 24. Configuration Registers Description

Register Name																																																																							
<b>CTRL1</b>		<b>Serial Interface and Sensor Enable. Register Address: 2 (0x02)</b>																																																																					
Bits	Name	Default	Description																																																																				
7	SIM	1'b0	0: Enables 4-wire SPI interface 1: Enables 3-wire SPI interface																																																																				
6	SPI_AI	1'b0	0: Serial interface (SPI or I <sup>2</sup> C) address do not auto increment. 1: Serial interface (SPI or I <sup>2</sup> C) address auto increment																																																																				
5	SPI_BE	1'b1	0: SPI read data little endian 1: SPI read data big endian																																																																				
4:1	Reserved	4'b0	Reserved																																																																				
0	SensorDisable	1'b0	0: Enables internal 2 MHz oscillator 1: Disables internal 2 MHz oscillator																																																																				
<b>CTRL2</b>		<b>Accelerometer Settings: Address: 3 (0x03)</b>																																																																					
Bits	Name	Default	Description																																																																				
7	aST	1'b0	Enable Accelerometer Self Test.																																																																				
6:4	aFS<2:0>	3'b0	Set Accelerometer Full-scale: 000 - Accelerometer Full-scale = ±2 g 001 - Accelerometer Full-scale = ±4 g 010 - Accelerometer Full-scale = ±8 g 011 - Accelerometer Full-scale = ±16 g 1xx - N/A																																																																				
3:0	aODR<3:0> <sup>(13)</sup>	4'b0	Set Accelerometer Output Data Rate (ODR): <table border="1" style="margin-left: 20px;"> <thead> <tr> <th>Setting</th> <th>ODR Rate (Hz)</th> <th>Mode</th> <th>Duty Cycle</th> </tr> </thead> <tbody> <tr><td>0000</td><td>8000</td><td>Normal</td><td>100%</td></tr> <tr><td>0001</td><td>4000</td><td>Normal</td><td>100%</td></tr> <tr><td>0010</td><td>2000</td><td>Normal</td><td>100%</td></tr> <tr><td>0011</td><td>1000</td><td>Normal</td><td>100%</td></tr> <tr><td>0100</td><td>500</td><td>Normal</td><td>100%</td></tr> <tr><td>0101</td><td>250</td><td>Normal</td><td>100%</td></tr> <tr><td>0110</td><td>125</td><td>Normal</td><td>100%</td></tr> <tr><td>0111</td><td>62.5</td><td>Normal</td><td>100%</td></tr> <tr><td>1000</td><td>31.25</td><td>Normal</td><td>100%</td></tr> <tr><td>1001</td><td>N/A</td><td></td><td></td></tr> <tr><td>1010</td><td>N/A</td><td></td><td></td></tr> <tr><td>1011</td><td>N/A</td><td></td><td></td></tr> <tr><td>1100</td><td>128</td><td>Low Power</td><td>100%</td></tr> <tr><td>1101</td><td>21</td><td>Low Power</td><td>58%</td></tr> <tr><td>1110</td><td>11</td><td>Low Power</td><td>31%</td></tr> <tr><td>1111</td><td>3</td><td>Low Power</td><td>8.5%</td></tr> </tbody> </table>	Setting	ODR Rate (Hz)	Mode	Duty Cycle	0000	8000	Normal	100%	0001	4000	Normal	100%	0010	2000	Normal	100%	0011	1000	Normal	100%	0100	500	Normal	100%	0101	250	Normal	100%	0110	125	Normal	100%	0111	62.5	Normal	100%	1000	31.25	Normal	100%	1001	N/A			1010	N/A			1011	N/A			1100	128	Low Power	100%	1101	21	Low Power	58%	1110	11	Low Power	31%	1111	3	Low Power	8.5%
Setting	ODR Rate (Hz)	Mode	Duty Cycle																																																																				
0000	8000	Normal	100%																																																																				
0001	4000	Normal	100%																																																																				
0010	2000	Normal	100%																																																																				
0011	1000	Normal	100%																																																																				
0100	500	Normal	100%																																																																				
0101	250	Normal	100%																																																																				
0110	125	Normal	100%																																																																				
0111	62.5	Normal	100%																																																																				
1000	31.25	Normal	100%																																																																				
1001	N/A																																																																						
1010	N/A																																																																						
1011	N/A																																																																						
1100	128	Low Power	100%																																																																				
1101	21	Low Power	58%																																																																				
1110	11	Low Power	31%																																																																				
1111	3	Low Power	8.5%																																																																				

Table 24 Configuration Register Description (Continued)

Register Name																																																																							
<b>CTRL3</b>		<b>Gyroscope Settings: Address 4 (0x04)</b>																																																																					
Bits	Name	Default	Description																																																																				
7	gST	1'b0	Enable Gyro Self-Test.																																																																				
6:4	gFS<2:0>	3'b0	Set Gyroscope Full-scale: 000 - ±16 dps 001 - ±32 dps 010 - ±64 dps 011 - ±128 dps 100 - ±256 dps 101 - ±512 dps 110 - ±1024dps 111 - ±2048 dps																																																																				
3:0	gODR<3:0> <sup>(13)</sup>	4'b0	Set Gyroscope Output Data Rate (ODR): <table border="1" data-bbox="703 730 1321 1310"> <thead> <tr> <th>Setting</th> <th>ODR Rate (Hz)</th> <th>Mode</th> <th>Duty Cycle</th> </tr> </thead> <tbody> <tr><td>0000</td><td>8000</td><td>Normal</td><td>100%</td></tr> <tr><td>0001</td><td>4000</td><td>Normal</td><td>100%</td></tr> <tr><td>0010</td><td>2000</td><td>Normal</td><td>100%</td></tr> <tr><td>0011</td><td>1000</td><td>Normal</td><td>100%</td></tr> <tr><td>0100</td><td>500</td><td>Normal</td><td>100%</td></tr> <tr><td>0101</td><td>250</td><td>Normal</td><td>100%</td></tr> <tr><td>0110</td><td>125</td><td>Normal</td><td>100%</td></tr> <tr><td>0111</td><td>62.5</td><td>Normal</td><td>100%</td></tr> <tr><td>1000</td><td>31.25</td><td>Normal</td><td>100%</td></tr> <tr><td>1001</td><td>N/A</td><td></td><td></td></tr> <tr><td>1010</td><td>N/A</td><td></td><td></td></tr> <tr><td>1011</td><td>N/A</td><td></td><td></td></tr> <tr><td>1100</td><td>N/A</td><td></td><td></td></tr> <tr><td>1101</td><td>N/A</td><td></td><td></td></tr> <tr><td>1110</td><td>N/A</td><td></td><td></td></tr> <tr><td>1111</td><td>N/A</td><td></td><td></td></tr> </tbody> </table>	Setting	ODR Rate (Hz)	Mode	Duty Cycle	0000	8000	Normal	100%	0001	4000	Normal	100%	0010	2000	Normal	100%	0011	1000	Normal	100%	0100	500	Normal	100%	0101	250	Normal	100%	0110	125	Normal	100%	0111	62.5	Normal	100%	1000	31.25	Normal	100%	1001	N/A			1010	N/A			1011	N/A			1100	N/A			1101	N/A			1110	N/A			1111	N/A		
Setting	ODR Rate (Hz)	Mode	Duty Cycle																																																																				
0000	8000	Normal	100%																																																																				
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1110	N/A																																																																						
1111	N/A																																																																						
<b>CTRL4</b>		<b>Magnetometer Settings: Address: 5 (0x05)</b>																																																																					
Bits	Name	Default	Description																																																																				
7	Reserved	1'b0																																																																					
6:3	mDEV<3:0>	4'b0	Designate External Magnetometer Device: (supported devices listed in Section 11).																																																																				
2:0	mODR<2:0>	3'b0	Set Recommended Magnetometer Output Data Rate (ODR): <table border="1" data-bbox="850 1562 1273 1869"> <thead> <tr> <th>Setting</th> <th>ODR Rate (Hz)</th> </tr> </thead> <tbody> <tr><td>000</td><td>1000</td></tr> <tr><td>001</td><td>500</td></tr> <tr><td>010</td><td>250</td></tr> <tr><td>011</td><td>125</td></tr> <tr><td>100</td><td>62.5</td></tr> <tr><td>101</td><td>31.25</td></tr> <tr><td>110</td><td>N/A</td></tr> <tr><td>11x</td><td>N/A</td></tr> </tbody> </table>	Setting	ODR Rate (Hz)	000	1000	001	500	010	250	011	125	100	62.5	101	31.25	110	N/A	11x	N/A																																																		
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**Note:**

13. The accelerometer low power mode is only available when the gyroscope is disabled

Table 24 Configuration Register Description (Continued)

Register Name																			
<b>CTRL5</b>		<b>Sensor Data Processing Settings. Register Address: 6 (0x06)</b>																	
Bits	Name	Default	Description																
7	Reserved	1'b0																	
6:5	gLPF_MODE	2'b0	<table border="1"> <thead> <tr> <th>gLPF_MODE</th> <th>BW [Hz]</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>2.62% of ODR</td> </tr> <tr> <td>01</td> <td>3.59% of ODR</td> </tr> <tr> <td>10</td> <td>5.32% of ODR</td> </tr> <tr> <td>11</td> <td>14.0% of ODR</td> </tr> </tbody> </table>	gLPF_MODE	BW [Hz]	00	2.62% of ODR	01	3.59% of ODR	10	5.32% of ODR	11	14.0% of ODR						
			gLPF_MODE	BW [Hz]															
			00	2.62% of ODR															
			01	3.59% of ODR															
			10	5.32% of ODR															
11	14.0% of ODR																		
4	gLPF_EN	1'b0	0: Disable Gyroscope Low-Pass Filter. 1: Enable Gyroscope Low-Pass Filter with the mode given by gLPF_MODE.																
3	Reserved	1'b0																	
2:1	aLPF_MODE	2'b0	<table border="1"> <thead> <tr> <th>aLPF_MODE</th> <th>BW [Hz]</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>2.62% of ODR</td> </tr> <tr> <td>01</td> <td>3.59% of ODR</td> </tr> <tr> <td>10</td> <td>5.32% of ODR</td> </tr> <tr> <td>11</td> <td>14.0% of ODR</td> </tr> </tbody> </table>	aLPF_MODE	BW [Hz]	00	2.62% of ODR	01	3.59% of ODR	10	5.32% of ODR	11	14.0% of ODR						
			aLPF_MODE	BW [Hz]															
			00	2.62% of ODR															
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0	aLPF_EN	1'b0	0: Disable Accelerometer Low-Pass Filter. 1: Enable Accelerometer Low-Pass Filter with the mode given by aLPF_MODE.																
<b>CTRL6</b>		<b>Attitude Engine ODR and Motion on Demand: Address: 7 (0x07)</b>																	
Bits	Name	Default	Description																
7	sMoD	1'b0	0: Disables Motion on Demand. 1: Enables Motion on Demand (Requires sEN=1).																
6:3	Reserved	4'b0																	
2:0	sODR<2:0>	3'b0	Attitude Engine Output Data Rate (ODR)																
			<table border="1"> <thead> <tr> <th>Setting</th> <th>ODR Rate (Hz)</th> </tr> </thead> <tbody> <tr> <td>000</td> <td>1</td> </tr> <tr> <td>001</td> <td>2</td> </tr> <tr> <td>010</td> <td>4</td> </tr> <tr> <td>011</td> <td>8</td> </tr> <tr> <td>100</td> <td>16</td> </tr> <tr> <td>101</td> <td>32</td> </tr> <tr> <td>110</td> <td>64</td> </tr> </tbody> </table>	Setting	ODR Rate (Hz)	000	1	001	2	010	4	011	8	100	16	101	32	110	64
			Setting	ODR Rate (Hz)															
			000	1															
			001	2															
			010	4															
			011	8															
			100	16															
			101	32															
110	64																		

Table 24 Configuration Register Description (Continued)

Register Name			
<b>CTRL7</b>		<b>Enable Sensors and Configure Data Reads. Register Address: 8 (0x08)</b>	
Bits	Name	Default	Description
7	syncSmpl	1'b0	0: Disable syncSmpl mode 1: Enable syncSmpl mode
6	sys_hs	1'b0	1: High Speed Internal Clock 0: Clock based on ODR
5	Reserved	1'b0	
4	gSN	1'b0	0: Gyroscope in Full Mode (Drive and Sense are enabled). 1: Gyroscope in Snooze Mode (only Drive enabled). This bit is effective only when gEN is set to 1.
3	sEN	1'b0	0: Disable AttitudeEngine orientation and velocity increment computation 1: Enable AttitudeEngine orientation and velocity increment computation
2	mEN	1'b0	0: Magnetometer placed in Standby or Power-down Mode. 1: Enable Magnetometer
1	gEN	1'b0	0: Gyroscope placed in Standby or Power-down Mode. 1: Enable Gyroscope.
0	aEN	1'b0	0: Accelerometer placed in Standby or Power-down Mode. 1: Enable Accelerometer.
<b>CTRL8</b>		<b>Reserved – Special Settings. Register Address: 9 (0x09)</b>	
Bits	Name	Default	Description
7:0	Reserved	0x00	Not Used
<b>Register Name</b>			
<b>CTRL9</b>		<b>Host Commands. Register Address: 10 (0x0A), Referred to: CTRL 9 Functionality (Executing Pre-defined Commands)</b>	

## 5.5 FIFO Registers

Table 25. FIFO Control/Status/Data Registers

Register Name				
<b>FIFO_WTM_TH</b>		<b>FIFO Watermark Register Address: 19 (0x13)</b>		
Bits	Name	Default	Description	
7:0	FIFO_WTM	8'h0	Number of ODRs needed to trigger watermark	
<b>FIFO_CTRL</b>		<b>FIFO Control Register Address: 20 (0x14)</b>		
Bits	Name	Default	Description	
7	FIFO_RD_MODE	1'b0	This bit is automatically set by using a CTRL9 command to request the FIFO to read data out of FIFO via FIFO_DATA register. It must be cleared again after the data read is complete so that writing data to the FIFO can resume.	
6:4	Reserved	3'b0		
3:2	FIFO_SIZE	2'b0	FIFO_SIZE[1:0]	FIFO Sample Size
			00	16 samples
			01	32 samples
			10	64 samples
			11	128 samples
1:0	FIFO_MODE	2'b0	FIFO_MODE[1:0]	FIFO Sample Size
			00	Bypass (FIFO disable)
			01	FIFO
			10	Stream
			11	Stream to FIFO. In stream to FIFO mode, once motion/gesture interrupt event happens, content of FIFO will be emptied, pointers reset
<b>FIFO_SMPL_CNT</b>		<b>FIFO Sample Count Register Address: 21 (0x15)</b>		
Bits	Name	Default	Description	
7:0	FIFO_SMPL_CNT_LSB	8'b0	8 LS bits of FIFO Sample Count (in bytes).	
<b>FIFO_STATUS</b>		<b>FIFO Status. Register Address 22 (0x16)</b>		
Bits	Name	Default	Description	
7	FIFO_FULL	1'b0	0 – FIFO is not Full 1 -- FIFO is Full	
6	FIFO_WTM	1'b0	0 -- FIFO Water Mark Level not hit. 1 – FIFO Water Mark Level Hit	
5	FIFO_OVERFLOW	1'b0	0 – FIFO Overflow has not happened 1 -- FIFO Overflow condition has happened (attempt to save ODR data to FIFO when it is full)	
4	FIFO_NOT_EMPTY	1'b0	0 – FIFO is Empty 1 -- FIFO is not Empty	
3:2	Reserved	2'b0		
1:0	FIFO_SMPL_CNT_MSB	2'b0	2 MS bits of FIFO Sample Count (in bytes).	

FIFO_DATA		FIFO DATA Output Register Address: 23 (0x17)	
Bits	Name	Default	Description
7:0	FIFO_DATA	8'b0	8 bit FIFO data output.

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## 5.6 Status and Time Stamp Registers

Table 26. Status and Time Stamp Registers

Register Name			
<b>I2CM_STATUS</b>		<b>I<sup>2</sup>C Master Status, Register Address: 44 (0x2C)</b>	
Bits	Name	Default	Description
7:3	Reserved	5'b0	
2	I2CM_done	1'b0	0: I <sup>2</sup> C Master data movement not complete (ARM still processing) 1: I <sup>2</sup> C Master data movement is complete (ARM has finished)
1	Data_VLD	1'b0	0: Magnetometer data is NOT Valid 1: Indicates Magnetometer X, Y, Z axes data is available and valid. This signal is asserted at the next ODR pulse and de-asserted on I <sup>2</sup> C read of the next cycle.
0	I2CM_active	1'b0	0: I <sup>2</sup> C Master transaction with peripheral is not done. 1: Indicate I <sup>2</sup> C Master transaction with peripheral is done.
<b>STATUSINT</b>		<b>Sensor Data Available and Lock Register Address: 45 (0x2D)</b>	
Bits	Name	Default	Description
7:2	Reserved	5'b0	
1	Locked	1'b0	If syncSmpl = 1 (Bit 7 in CTRL7) then: 0: Sensor Data not locked. 1: Sensor Data Locked. If syncSmpl = 0 then bit 1 will have the same value of the Interrupt in INT1.
0	Avail	1'b0	If syncSmpl = 1 (Bit 7 in CTRL7) then: 0: Sensor Data not available 1: Sensor Data available for reading If syncSmpl = 0 then bit 0 will have the same value of the Interrupt in INT2.
<b>STATUS0</b>		<b>Output Data Status Register Address: 46 (0x2E)</b>	
Bits	Name	Default	Description
7:4	Reserved	4'b0	
3	sDA	1'b0	AE new data available 0: No updates since last read. 1: New data available.
2	mDA	1'b0	Valid Magnetometer data available 0: Magnetometer data is NOT Valid 1: Valid Magnetometer data is available at every ODR. If Mag ODR is lower than accelerometer and gyroscope ODR previous valid Magnetometer data will be repeated until new data is available
1	gDA	1'b0	Gyroscope new data available 0: No updates since last read. 1: New data available.
0	aDA	1'b0	Accelerometer new data available 0: No updates since last read. 1: New data available.
<b>STATUS1</b>		<b>Miscellaneous Status. Register Address 47 (0x2F)</b>	

Bits	Name	Default	Description
7:1	Reserved	7'b0	Reserved
0	CmdDone	1'b0	Bit read by Host Processor as part of CTRL9 register protocol. Used to indicate ctrl9 Command was done.
<b>TIMESTAMP</b>		<b>3 Bytes Sample Time Stamp – Output Count. Register Address: 48 - 50 (0x30 - 0x32)</b>	
Bits	Name	Default	Description
7:0	TIMESTAMP_L<7:0>	0x00	Sample time stamp. Count incremented by one for each sample (x, y, z data set) from sensor with highest ODR (circular register 0x0-0xFFFFF).
7:0	TIMESTAMP_M<15:8>	0x00	
7:0	TIMESTAMP_H<23:16>	0x00	

## 5.7 Sensor Data Output Registers

Table 27. Sensor Data Output Registers Description

Register Name			
<b>TEMP_[H,L]</b>		<b>Temp Sensor Output. Register Address: 51 – 52, (0x33 – 0x34)</b>	
Bits	Name	Default	Description
7:0	TEMP_L	0x00	Temperature output (°C) in two's complement.
7:0	TEMP_H	0x00	
Register Name			
<b>A[X,Y,Z]_[H,L]</b>		<b>Acceleration Output. Register Address: 53 – 58, (0x35 – 0x3A)</b>	
Bits	Name	Default	Description
7:0	AX_L<7:0>	0x00	X-axis acceleration in two's complement. AX_L – lower 8 bits. AX_H – upper 8 bits.
7:0	AX_H<15:8>	0x00	
7:0	AY_L<7:0>	0x00	Y-axis acceleration in two's complement. AY_L – lower 8 bits. AY_H – upper 8 bits.
7:0	AY_H<15:8>	0x00	
7:0	AZ_L<7:0>	0x00	Z-axis acceleration in two's complement. AZ_L – lower 8 bits. AZ_H – upper 8 bits.
7:0	AZ_H<15:8>	0x00	
Register Name			
<b>G[X,Y,Z]_[H,L]</b>		<b>Angular Rate Output. Register Address: 59 – 64 (0x3B – 0x40)</b>	
Bits	Name	Default	Description
7:0	GX_L<7:0>	0x00	X-axis angular rate in two's complement. GX_L – lower 8 bits. GX_H – upper 8 bits.
7:0	GX_H<15:8>	0x00	
7:0	GY_L<7:0>	0x00	Y-axis angular rate in two's complement. GY_L – lower 8 bits. GY_H – upper 8 bits.
7:0	GY_H<15:8>	0x00	
7:0	GZ_L<7:0>	0x00	Z-axis angular rate in two's complement. GZ_L – lower 8 bits. GZ_H – upper 8 bits.
7:0	GZ_H<15:8>	0x00	
Register Name			
<b>M[X,Y,Z]_[H,L]</b>		<b>Magnetometer Output. Register Address: 65 - 70. (0x41 – 0x46)</b>	
Bits	Name	Default	Description
7:0	MX_L<7:0>	0x00	X-axis magnetic field data in two's complement. MX_L – lower 8 bits. MX_H – upper 8 bits.
7:0	MX_H<15:8>	0x00	
7:0	MY_L<7:0>	0x00	Y-axis magnetic field data in two's complement. MY_L – lower 8 bits. MY_H – upper 8 bits.
7:0	MY_H<15:8>	0x00	
7:0	MZ_L<7:0>	0x00	Z-axis magnetic field data in two's complement. MZ_L – lower 8 bits. MZ_H – upper 8 bits.
7:0	MZ_H<15:8>	0x00	

Continued on the following page

Table 27 Sensor Data Output Registers Description (Continued)

Register Name			
<b>dQ[1,2,3,4]_[H,L]</b>		<b>Quaternion Output. Register Addresses: 73 – 80 (0x49 – 0x50)</b>	
Bits	Name	Default	Description
7:0	dQW_L<7:0>	0x00	Quaternion Increment dQW in two's complement. dQW_L – lower 8 bits. dQW_H – upper 8 bits.
7:0	dQW_H<15:8>	0x00	
7:0	dQX_L<7:0>	0x00	Quaternion Increment dQX in two's complement. dQX_L – lower 8 bits. dQX_H – upper 8 bits.
7:0	dQX_H<15:8>	0x00	
7:0	dQY_L<7:0>	0x00	Quaternion Increment dQY in two's complement. dQY_L – lower 8 bits. dQY_H – upper 8 bits.
7:0	dQY_H<15:8>	0x00	
7:0	dQZ_L<7:0>	0x00	Quaternion Increment dQZ in two's complement. dQZ_L – lower 8 bits. dQZ_H – upper 8 bits.
7:0	dQZ_H<15:8>	0x00	
<b>dV[X,Y,Z]_[H,L]</b>		<b>Delta Velocity Output. Register Address: 81 – 86 (0x51– 0x56)</b>	
Bits	Name	Bits	Name
7:0	dVX_L<7:0>	0x00	X-axis Velocity Increment in two's complement. dVX_L – lower 8 bits. dVX_H – upper 8 bits.
7:0	dVX_H<15:8>	0x00	
7:0	dVY_L<7:0>	0x00	Y-axis Velocity Increment in two's complement. dVY_L – lower 8 bits. dVY_H – upper 8 bits.
7:0	dVY_H<15:8>	0x00	
7:0	dVZ_L<7:0>	0x00	Z-axis Velocity Increment in two's complement. dVZ_L – lower 8 bits. dVZ_H – upper 8 bits.
7:0	dVZ_H<15:8>	0x00	
<b>AE_REG1</b>		<b>AttitudeEngine Register 1, Address: 87 (0x57)</b>	
Bits	Name	Default	Description
7	Reserved	1'b0	
6	GyroBiasAck	1'b0	Acknowledgement that Gyro Bias was updated during this time period.
5	wz_clip	1'b0	Gyroscope Z-axis data was clipped during the dQ calculation.
4	wy_clip	1'b0	Gyroscope Y-axis data was clipped during the dQ calculation.
3	wx_clip	1'b0	Gyroscope X-axis data was clipped during the dQ calculation.
2	az_clip	1'b0	Accelerometer Z-axis data was clipped during the dQ calculation.
1	ay_clip	1'b0	Accelerometer Y-axis data was clipped during the dQ calculation.
0	ax_clip	1'b0	Accelerometer X-axis data was clipped during the dQ calculation.

Table 27 Sensor Data Output Registers Description (Continued)

Register Name			
<b>AE_REG2</b>		<b>AttitudeEngine Register 2, Address: 88 (0x58)</b>	
Bits	Name	Default	Description
7:3	Reserved	5'b0	
2	dvz_of	1'b0	Velocity Increment overflow along dvz.
1	dvy_of	1'b0	Velocity Increment overflow along dvy.
0	dvx_of	1'b0	Velocity Increment overflow along dvx.

Table 28. AttitudeEngine Modes and Output Table

Mode/Outputs		dQ	dV	M	TIMESTAMP	Comments on TIMESTAMP
<b>AttitudeEngine in ODR Mode (Accelerometer and Gyroscope Enabled)</b>						
CTRL6 Register	sMoD=0	Quaternion Increment	Velocity Increment	No Data	AttitudeEngine Sample Count	24-bit data. Count starts at 1, 16,777,216 count wraps to 0, i.e. Mod(16,777,216)
CTRL7 Register	gSN=0					
	sEN=1					
	aEN=1					
	gEN=1					
	mEN=0					
<b>AttitudeEngine in Motion on Demand (MoD) mode (Accelerometer and Gyroscope enabled)</b>						
CTRL6 Register	sMoD=1	Quaternion Increment	Velocity Increment	No Data	Gyroscope Samples in Integration Window	24-bit data. Count starts at 1, 16,777,216 count wraps to 0, i.e. Mod(16,777,216)
CTRL7 Register	gSN=0					
	sEN=1					
	aEN=1					
	gEN=1					
	mEN=0					
<b>AttitudeEngine with Raw Magnetometer in ODR Mode (Accelerometer, Gyroscope and Magnetometer Enabled)</b>						
CTRL6 Register	sMoD=0	Quaternion Increment	Velocity Increment	Initial Raw Mag Data	AttitudeEngine Sample Count	24-bit data. Count starts at 1, 16,777,216 count wraps to 0, i.e. Mod(16,777,216)
CTRL7 Register	gSN=0					
	sEN=1					
	aEN=1					
	gEN=1					
	mEN=1					

## 5.8 CTRL 9 Functionality (Executing Pre-defined Commands)

### 5.8.1 CTRL 9 Description

The protocol for executing predefined commands from an external host processor on the QMI8658C is facilitated by using the Control 9 (CTRL9) register. The register is available to the host via the UI SPI/I<sup>2</sup>C/I3C bus. It operates by the host writing a pre-defined value (Command) to the CTRL9 register. The firmware of the QMI8658C evaluates this command and if a match is found it executes the corresponding pre-defined function. Once the function has been executed, the QMI8658C signals the completion of this by raising INT1 interrupt. The host must acknowledge this by reading STATUS1 register bit 0. This is the CmdDone bit. After this read, the QMI8658C pulls down the INT1 interrupt. This command presentation from the host to the QMI8658C and the subsequent execution and handshake between the host and the QMI8658C will be referred to as the “CTRL9 Protocol”.

There are three types of interactions between the host and QMI8658C that follow the CTRL9 Protocol.

**WCtrl9:** The host needs to supply data to QMI8658C prior to the Ctrl9 protocol. (**Write – Ctrl9 Protocol**)

**Ctrl9R:** The host gets data from QMI8658C following the Ctrl9 protocol. (**Ctrl9 protocol – Read**)

**Ctrl9:** No data transaction is required prior to or following the Ctrl9 protocol. (**Ctrl9**).

### 5.8.2 WCtrl9 (Write – CTRL9 Protocol)

1. The host needs to provide the required data for this command to the QMI8658C. The host typically does this by placing the data in a set of registers called the CAL buffer. Eight CAL registers are used; the following table provides the name and addresses of these registers.
2. Write Ctrl9 register 0x0a with the appropriate Command value.
3. The Device will raise INT1 and set Bit 0 in STATUS1 reg, to 1 once it has executed the appropriate function based on the command value.
4. The host must acknowledge this by reading STATUS1 register bit 0 (CmdDone) which is reset to 0 on reading the register. In addition, INT1 is pulled low, completing the CTRL9 transaction.
5. If any data is expected from the device, it will be available at this time. The location of the data is specified separately for each of the Commands.

Table 29. CAL Register Addresses

Register Name	Register Address	
	Dec	Hex
CAL1_L	11	0x0B
CAL1_H	12	0x0C
CAL2_L	13	0x0D
CAL2_H	14	0x0E
CAL3_L	15	0x0F
CAL3_H	16	0x10
CAL4_L	17	0x11
CAL4_H	18	0x12

**5.8.3 Ctrl9R (CTRL9 Protocol - Read)**

1. Write Ctrl9 register 0x0A with the appropriate Command value.
2. The Device will raise INT1 and set Bit 0 in STATUS1 register to 1 once it has executed the appropriate function based on the command value.
3. The host must acknowledge this by reading STATUS1 register bit 0 (CmdDone) which is then reset to 0 upon reading the register. In addition, INT1 is pulled low upon the register read, completing the CTRL9 transaction.  
Data is available from the device at this time. The location of the data is specified separately for each of the Commands.

**5.8.4 Ctrl9 (CTRL9 Protocol Acknowledge)**

1. Write CTRL9 register 0x0a with the appropriate Command value.
2. The Device will raise INT1 and set Bit 0 in STATUS1 register to 1 once it has executed the appropriate function based on the command value.
3. The host must acknowledge this by reading STATUS1 register bit 0 (CmdDone) which is then reset to 0 upon reading the register. In addition, INT1 is pulled low upon the register read, completing the CTRL9 transaction.

Table 30. CTRL9 Register CMND Values

CMND Name	CTRL9 Command Value	Protocol Type	Description
CTRL_CMD_NOP	0x00	Ctrl9	No operation
CTRL_CMD_GYRO_BIAS	0x01	WCtrl9	Copies bias_gx,y,z from CAL registers to FIFO and set GYROBIAS_PEND bit
CTRL_CMD_REQ_SDI	0x03	Ctrl9R	SDI MOD (Motion on Demand), request to read SDI data
CTRL_CMD_RST_FIFO	0x04	Ctrl9	Reset FIFO from Host
CTRL_CMD_REQ_FIFO	0x05	Ctrl9R	Get FIFO data from Device
CTRL_CMD_I2CM_WRITE	0x06	WCtrl9	Program device on I <sup>2</sup> C Master Bus (I2CM) by writing to CAL1_[H,L], CAL2_[H,L], and CAL3_L registers.
CTRL_CMD_WRITE_WOM_SETTING	0x08	WCtrl9	Set up and enable Wake on Motion (WoM)
CTRL_CMD_ACCEL_HOST_DELTA_OFFSET	0x09	WCtrl9	Change accelerometer offset
CTRL_CMD_GYRO_HOST_DELTA_OFFSET	0x0A	WCtrl9	Change gyroscope offset
CTRL_CMD_COPY_USID	0x10	Ctrl9R	Read USID_Bytes and FW_Version bytes
CTRL_CMD_SET_RPU	0x11	WCtrl9	Configures IO pull-ups

## 5.8.5 CTRL9 Commands in Detail

### CTRL\_CMD\_NOP

No Operation

### CTRL\_CMD\_GYRO\_BIAS

This CTRL9 Command is issued to copy bias\_gx, bias\_gy, bias\_gz from CAL registers to FIFO and set GYROBIAS\_PEND bit. CAL3\_[H,L] is bias\_gz, CAL2\_[H,L] is bias\_gy, CAL1\_[H,L] is bias\_gx.

### CTRL\_CMD\_REQ\_SDI

This CTRL9 command is used to retrieve motion data from the QMI8658C when Motion on Demand mode (MoD) is enabled. To enable MoD the device should have the AttitudeEngine orientation enabled. This can be done by enabling the AttitudeEngine by setting CTRL7 Bit 3 (sEN) to 1. Then the MoD mode can be enabled by setting CTRL6 Bit 7 (sMoD) to 1. The CTRL\_CMD\_REQ\_MoD command is then issued by writing 0x0C to CTRL9 register 0x0A. This indicates to the QMI8658C that it is required to supply the motion data to the host. The device immediately makes available the orientation and velocity increments it has computed so far to the host by making them available at output registers 0x25 to 0x3D and raises the INT1 to indicate to the host that valid data is available.

### CTRL\_CMD\_RST\_FIFO

This CTRL9 command of writing 0x05 to the Ctrl9 register 0x0a allows the host to instruct the device to reset the FIFO.

### CTRL\_CMD\_REQ\_FIFO

This CTRL9 Command is issued when the host wants to get data from the FIFO. When the FIFO is enabled it will be indicated to the host by asserting INT2 and thus signaling that a flag condition (like FIFO full) has been reached and that data is available to be read by the host. This Command is issued by writing 0x0D to the CTRL9 register 0x0A. The device will raise INT1 to indicate that it is ready for a FIFO transaction. The host must read the STATUS1 register bit 0 (CmdDone). At this point the host should set the FIFO\_rd\_mode Bit to 1 (FIFO\_CTRL register 0x13 bit 7). The device will direct the FIFO data to the FIFO\_DATA register 0x14 until the FIFO is empty. The host must now set FIFO\_rd\_mode to 0, which will cause the INT2 to be de-asserted.

### CTRL\_CMD\_I2CM\_WRITE

This CTRL9 command of writing 0x06 to the Ctrl9 register 0x0a allows the host to instruct the device to Program I2CM by writing to CAL1\_[H,L], CAL2\_[H,L], and CAL3\_L registers. CAL3\_L is address offset, CAL2\_[H,L] is register data[31:16], CAL1\_[H,L] is register data[15:0]. This Command is used to configure the I<sup>2</sup>C master, and to execute an I<sup>2</sup>C write or read command.

### CTRL\_CMD\_WRITE\_WOM\_SETTING

This CTRL9 Command is issued when the host wants to enable/modify the trigger thresholds or blanking interval of the Wake on Motion Feature of the device. Please refer to Section 9 for details for setting up this feature. Once the specified CALx registers are loaded with the appropriate data, the Command is issued by writing 0x08 to CTRL9 register 0x0A.

### CTRL\_CMD\_ACCEL\_HOST\_DELTA\_OFFSET

This CTRL9 Command is issued when the host wants to manually change the accelerometer offset. Each delta offset value should contain 16 bits and the format is signed 4.12 (12 fraction bits). The user must write the offset to the following registers:

```
Accel_Delta_X : {CAL1_H, CAL1_L}
Accel_Delta_Y : {CAL2_H, CAL2_L}
Accel_Delta_Z : {CAL3_H, CAL3_L}
```

Next, the Command is issued by writing 0x09 to CTRL9 register 0x0A. Note, this offset change is lost when the sensor is power cycled or the system is reset.

### CTRL\_CMD\_GYRO\_HOST\_DELTA\_OFFSET

This CTRL9 Command is issued when the host wants to manually change the gyroscope offset. Each delta offset value should contain 16 bits and the format is signed 11.5 (5 fraction bits). The user must write the offset to the following registers:

```
Gyro_Delta_X : {CAL1_H, CAL1_L}
Gyro_Delta_Y : {CAL2_H, CAL2_L}
Gyro_Delta_Z : {CAL3_H, CAL3_L}
```

Next, the Command is issued by writing 0x0A to CTRL9 register 0x0A. Note, this offset change is lost when the sensor is power cycled or the system is reset.

### CTRL\_CMD\_COPY\_USID

This CTRL9 Command copies the following data into UI registers. It is initiated by the host writing 0x10 to CTRL9. After issuing the command, the data will be available for the host to read from the registers shown below:

```
FW_Version byte 0 → dQW_L
FW_Version byte 1 → dQW_H
FW_Version byte 2 → dQX_L
USID_Byte_0 → dVX_L
USID_Byte_1 → dVX_H
USID_Byte_2 → dVY_L
USID_Byte_3 → dVY_H
USID_Byte_4 → dVZ_L
USID_Byte_5 → dVZ_H
```

### CTRL\_CMD\_SET\_RPU

This CTRL9 Command is issued when the host wants to manually configure the IO pull-up resistors. Each bit controls a unique resistor as shown:

aux_rpu_dis:	CAL1_L bit[0]
icm_rpu_dis:	CAL1_L bit[1]
cs_rpu_dis:	CAL1_L bit[2]
ics_rpu_dis:	CAL1_L bit[3]

The host writes the appropriate CAL1\_L bit by issuing a WCtrl9 command to 0x11.

## 6 Interrupts

### 6.1 Overview

The QMI8658C has two Interrupt lines, INT1 and INT2. INT1 is used as a general-purpose interrupt. The details are described in the specific sections where INT1 and INT2 are used. The following provides a summary of the INT1 and INT2 usage. If `syncSmpl = 0`, then bit 1 of STATUSINT register will have the same value as INT1 and bit 0 of STATUSINT register will have the same value as INT2.

#### 6.1.1 Interrupt 1 (INT1)

The following summarizes the use of INT1:

Set high for ~4 ms after reset to indicate that the chip is ready for normal operation.

If any operation has set INT1 it will always be cleared by reading STATUS1 register.

Used as part of the CTRL9 handshake protocol (see section 5.8).

When Wake on Motion (WoM) is enabled, INT1 can be selected to indicate WoM (see section 9).

#### 6.1.2 Interrupt 2 (INT2)

INT2 generally indicates data availability.

When Wake on Motion (WoM) is enabled, INT2 can be selected to indicate WoM (see section 9).

The following indicates when INT2 will be asserted.

##### **Register-Read Mode (FIFO Bypass Mode)**

In Register-Read mode the accelerometer, gyroscope and magnetometer data are available in the Sensor Data Output registers (A[X,Y,Z]\_[H,L]). The updating of these output registers and the functionality of the INT2 interrupt is controlled by the `syncSmpl` bit as described below.

With `syncSmpl = 0` (refer to Table 24, CTRL7 register bit 7), INT2 is placed into edge trigger mode: the Sensor Data Output Registers are updated at the Output Data Rate (ODR), and INT2 is pulsed at the ODR. A rising edge on INT2 indicates that data is available and INT2 is cleared automatically after a short duration. It is the responsibility of the host to detect the rising edge and to latch the data before the next sample occurs. Note that the INT2 pulse width is dependent on the ODR and the sensor. It is not recommended to depend on the level to determine if INT2 has occurred.

With `syncSmpl = 1` (refer to Table 24, CTRL7 register bit 7), INT2 is placed into level mode: The INT2 is asserted when data is available and remains asserted until the host reads STATUS0 register.

The device continues to refresh the output data until the STATUS0 register is read by host.

Once the STATUS0 is read by host the QMI8658C will deassert INT2 and stop refreshing the output data. Once the host detects INT2 has been deasserted it can start reading the output data.

Once the last byte of data has been read by the host (the QMI8658C keeps track) the QMI8658C will start updating the output register and set up the next INT2 when data is available in the output registers.

##### **FIFO Enabled Mode (see Section 8)**

When the FIFO is enabled in the **FIFO mode** (the mode bits in FIFO\_CTRL register set to 01), INT2 is asserted when the FIFO is full or when the watermark is reached.

When the FIFO is enabled in the **Streaming Mode** (the mode bits in FIFO\_CTRL register set to 10), INT2 is asserted when the watermark is reached but not when the FIFO is full because in the stream mode the FIFO will continue to fill by overwriting the oldest data in the FIFO.

INT2 is cleared in both the FIFO Mode and the Streaming Mode by clearing the `FIFO_rd_mode` bit in the FIFO\_CTRL register. This is done as part of the CTRL9 command `CTRL_CMD_REQ_FIFO`.

##### **Accelerometer and Gyroscope Self Test Modes (see Section 10)**

INT2 is asserted to indicate availability of self-test data and is cleared by resetting the `aST` and `gST` bits in CTRL2 and CTRL3 registers, respectively.

##### **AE Mode**

In AE Mode, INT2 is asserted when data is available.

## 7 Operating Modes

The QMI8658C offers a large number of operating modes that may be used to operate the device in a power efficient manner. These modes are described in Table 31

and are shown in Figure 8; they may be configured using the control (CTRL) registers.

Table 31. Operating Modes

Mode	Description	Suggested Configuration
<b>Sensor Modes</b>		
<b>Power-On Default</b>	All sensors off, clock is turned on. The current in this mode is typically 50 $\mu$ A. Note this mode is the default state upon initial power up or after a reset.	CTRL1 sensorDisable = 0 CTRL7 aEN = 0, gEN = 0, mEN = 0, sEN=0. CTRL2 aODR =000
<b>Low Power</b>	Same as Power-On Default mode, except in this mode the 250 kHz clock is turned on instead of the 2 MHz clock. The current in this mode is typically 25 $\mu$ A. To enter this mode requires host interaction to set CTRL2 aODR=11xx.	CTRL1 sensorDisable =0 CTRL7 aEN = 0, gEN = 0, mEN = 0, sEN=0. CTRL2 aODR =11xx
<b>Power-Down</b>	All QMI8658C functional blocks are switched off to minimize power consumption. Digital interfaces remain on allowing communication with the device. All configuration register values are preserved, and output data register values are maintained. The current in this mode is typically 20 $\mu$ A. The host must initiate this mode by setting sensorDisable=1.	CTRL1 sensorDisable =1 CTRL7 aEN = 0, gEN = 0, mEN = 0, sEN=0.
<b>Normal Accel Only</b>	Device configured as an accelerometer only.	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR !=11xx
<b>Low Power Accel Only</b>	Device configured in low power accelerometer mode.	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR =11xx
<b>Snooze Gyro</b>	Device configured as gyroscope Drive only, since the Sense is not enabled, there is no data from the gyroscope in this mode.	CTRL7 gSN=1, aEN =0, gEN =1, mEN =0
<b>Gyro Only</b>	Device configured as a gyroscope only.	CTRL7 gSN=0, aEN =0, gEN =1, mEN =0
<b>Mag Only</b>	Device configured as a magnetometer only.	CTRL7 aEN =0, gEN =0, mEN =1
<b>Accel + Mag</b>	Device configured as an accelerometer and magnetometer combination only. Device can be used as a (stabilized) compass.	CTRL7aEN =1, gEN =0, mEN =1 CTRL2 aODR != 11xx
<b>Accel + Gyro (IMU)</b>	Device configured as an Inertial Measurement Unit, i.e. an accelerometer and gyroscope combination sensor.	CTRL7 gSN=0, aEN =1, gEN =1, mEN =0 CTRL2 aODR != 11xx
<b>Accel + Gyro + Mag (9DOF)</b>	Accelerometer and gyroscope are enabled and combined with an external magnetometer and the device can be used as a 9D orientation sensor (Attitude and Heading Reference).	CTRL7 gSN=0, aEN =1, gEN =1, mEN =1 CTRL2 aODR != 11xx
<b>Accel + Snooze Gyro</b>	Accelerometer and gyroscope snooze are enabled. Only accelerometer data is available.	CTRL7 gSN=1, aEN =1, gEN =1, mEN =0 CTRL2 aODR != 11xx
<b>Accel + Mag + Snooze Gyro</b>	Accelerometer and gyroscope snooze are enabled. Only accelerometer and magnetometer data are available.	CTRL7 gSN=1, aEN =1, gEN =1, mEN =1 CTRL2 aODR != 11xx
<b>Wake on Motion (WoM)</b>	Very low power mode used to wake-up the host by providing an interrupt upon detection of device motion.  WoM Mode enabled - see CTRL_CMD_WRITE WOM_SETTING in Section 5.8.5 and	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR = 11xx

	see Section 9, Wake on Motion (WoM)	
--	-------------------------------------	--

Table 31 Operating Modes (Continued)

Mode	Description	Suggested Configuration
<b>Sensor Modes</b>		
<b>Reset</b>	Software reset asserted	
<b>No Power</b>	VDDIO and VDD low	
<b>AttitudeEngine Modes</b>		
<b>6DOF AttitudeEngine Mode</b>	Attitude Engine Mode with Accelerometer and Gyroscope. Note that velocity increments and orientation (quaternion) increments will be output rather than sensor values.	CTRL7 aEN = 1, gEN = 1, sEN = 1 CTRL2 aODR=0xx
<b>9DOF AttitudeEngine Mode</b>	AttitudeEngine Mode with Accelerometer, Gyroscope, and Magnetometer. Note that velocity increments, orientation (quaternion) increments and magnetic field values will be output rather than sensor values.	CTRL7 aEN = 1, gEN = 1, sEN = 1, mEN = 1 CTRL4 (configure magnetometer as needed)
<b>Motion On Demand Mode</b>	This mode allows Host to sample AttitudeEngine data asynchronously by polling.	CTRL7 aEN = 1, gEN = 1, sEN = 1 CTRL6 sMOD = 1

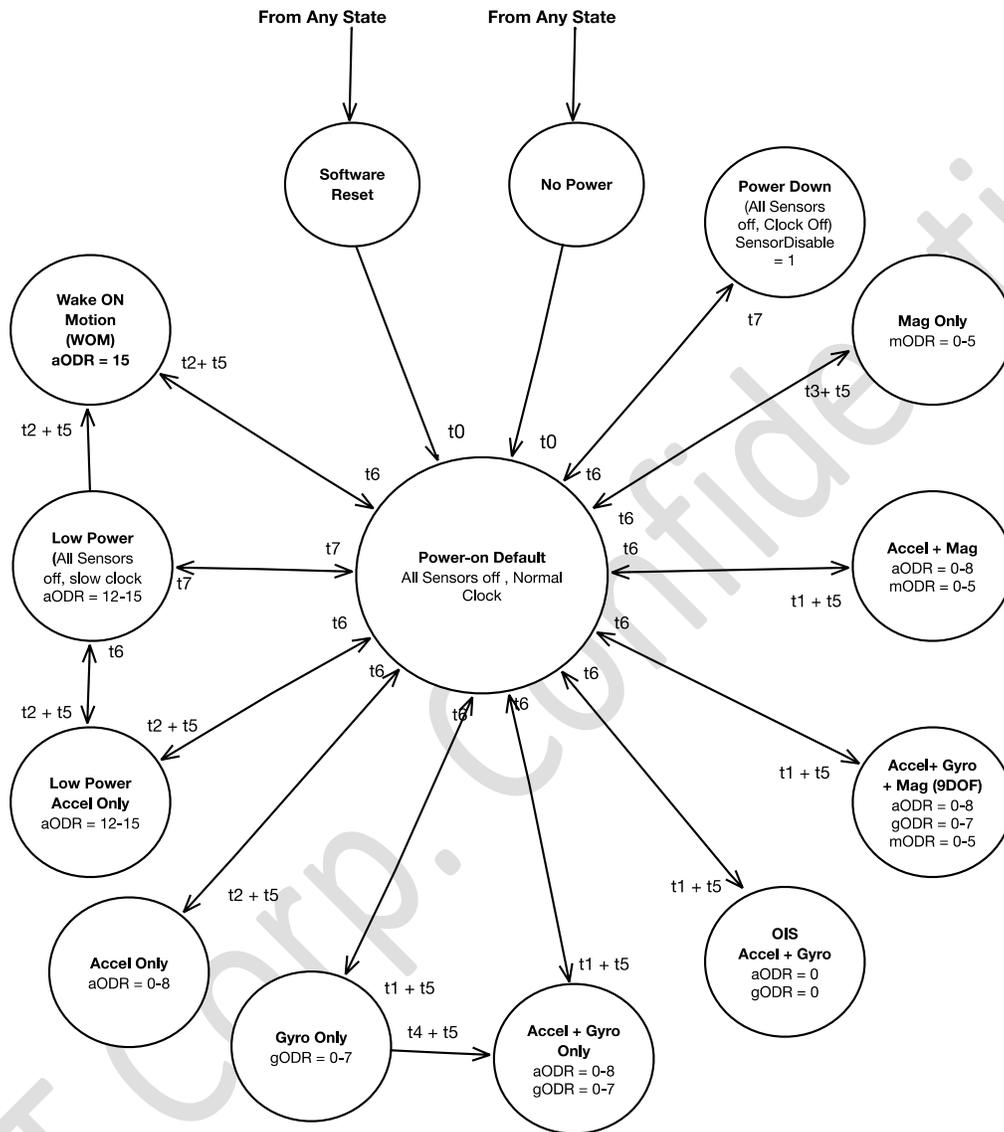


Figure 8. Operating Mode Transition Diagram

## 7.1 General Mode Transitioning

Upon exiting the No Power state (i.e. on first applying power to the part) or exiting a Software Reset state, the part will enter the Power-On Default state. From there, the sensor can be configured in the various modes described in Table 31 and as shown in Figure 8. The figure illustrates the timing associated with various mode transitions, and values for these times are given in the section below and in Table 7 and Table 8.

## 7.2 Transition Times

The time it takes for data to be present after a mode switch will vary and depends on which mode has been selected. For example, the time it takes for retrieving data from the accelerometer after a mode switch is less than any mode that involves the gyroscope. The times  $t_1$ ,  $t_2$ ,  $t_3$  and  $t_4$ , are defined as the time it takes from INT2 going high to data being present. The time,  $t_5$  is the time it takes to have a correct representation of the inertial state.  $t_5$  is variable and is associated with the user selected Output Data Rate (ODR). We have defined  $t_5 = (3/ODR)$  to generally represent that time.

$t_6$  is the time it takes to go from a sensor powered state to a state where the sensors are off. This time depends on the Output Data Rate (ODR) and ranges from  $1/ODR$  to  $2/ODR$ .

$t_7$  is the transition time between various states where the sensors are off.

$t_0$  is the *System Turn On Time*, and is the time to enter the Power-On Default state from Software Reset, No Power, or Power down.

- Time  $t_0$  is the *System Turn on Time* and is 1.75 seconds. This time only needs to be done once, upon transitioning from either a No Power or Power Down state, or whenever a reset is issued, which should not be done unless the intent is to have the device to go through its entire boot sequence (see the specification *System Turn On Time* in both Table 7 and Table 8).
- The *Gyro Turn on Time* (see Table 8) is comprised of  $t_1$  (the gyroscope wakeup time) and  $t_5$  (the part's filter settling time).  $t_1$  is typically 60 ms and  $t_5$  is defined as  $3/ODR$ , where ODR is the output data rate in Hertz.
- The *Accel Turn on Time* (see Table 7) is comprised of  $t_2$  (the accelerometer wakeup time) and  $t_5$  (the part's filter settling time).  $t_2$  is typically 3 ms, and  $t_5$  is defined as  $3/ODR$ , where ODR is the output data rate in Hertz.
- Time  $t_3$  is the magnetometer wakeup time, which is typically 12 ms. Transitioning from the Power-On Default state to a Mag Only state or a Mag + Accel state takes the time  $t_3 + t_5$ , where  $t_5$  is defined as  $3/ODR$ , where ODR is the output data rate in Hertz.
- The  $t_7$  transition is dependent on data transfer rates and is for I2C at 400 kHz is  $<100 \mu\text{s}$  for SPI at 11 Mbps is around  $40 \mu\text{s}$ .

## 8 FIFO Description

### 8.1 Using the FIFO

The QMI8658C contains a programmable 1536-byte data buffer, which can be used as a FIFO buffer. The FIFO's operating mode and configuration are set via the FIFO\_CTRL register. FIFO data may consist of gyroscope, accelerometer and magnetometer data and is accessible via the serial interfaces. The FIFO also supports burst reads. The host must complete its burst read prior to the next sensor data period. This time period is defined by the ODR selected. Depending on how many sensors are enabled, the host will need to read increments of 6, 12 or 18 bytes, corresponding to one, two and three sensors active at the same time. This feature helps reduce overall system power consumption by enabling the host processor to read and process the sensor data in bursts and then enter a low-power mode. The interrupt function may be used to alert when new data is available.

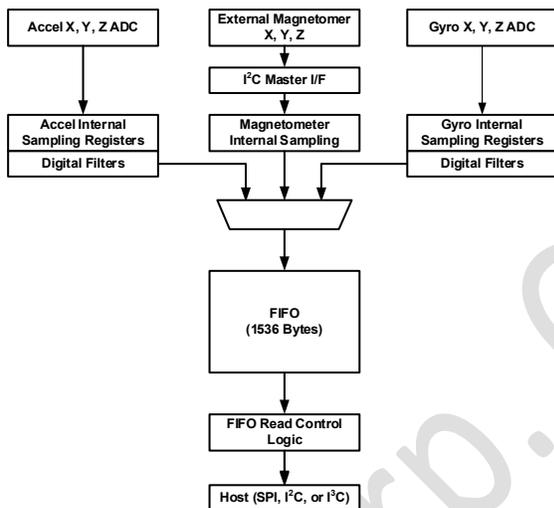


Figure 9. FIFO Data Flow

The FIFO size is configured using the FIFO\_CTRL register. When the FIFO is enabled for two or more sensors, as is true for all modes that have multiple sensors active, the sensors must be set at the same Output Data Rate (ODR).

The FIFO is read through the I3C/I²C/SPI interface by reading the FIFO\_DATA register. Any time the Output Registers are read, data is erased from the FIFO memory.

The FIFO has multiple operating modes: Bypass, FIFO, and Streaming. The operating modes are set using the mode<1:0> bits in the FIFO\_CTRL register.

#### Enabling FIFO

The FIFO is configured by writing to the FIFO\_CTRL register and is enabled after the accelerometer and/or gyroscope are enabled. If the watermark function is enabled in the FIFO\_CTRL register, pin INT2 is asserted when the FIFO watermark level is reached.

#### Reading Sensor Data from FIFO

Sensor data is read from the FIFO through the following command sequence. (For additional information, see CTRL9 description).

- Request access to FIFO data buffer by sending CTRL9 command 0x0D. This automatically sets FIFO\_rd\_mode bit to 1 in FIFO\_CTRL.
- Read FIFO\_DATA register to empty the FIFO.
- After FIFO is emptied, set FIFO\_rd\_mode bit to 0.

Note that when only the accelerometer or gyroscope is enabled, the sensor data format at the host interface is:

AX\_L[0] → AX\_H[0] → AY\_L[0] → AY\_H[0] → AZ\_L[0] → AZ\_H[0] → AX\_L[1] → ...

When 2 sensors are enabled, the sensor data format is:

AX\_L[0] → AX\_H[0] → AY\_L[0] → AY\_H[0] → AZ\_L[0] → AZ\_H[0] → GX\_L[0] → GX\_H[0] → GY\_L[0] → GY\_H[0] → GZ\_L[0] → GZ\_H[0] → AX\_L[1] → AX\_H[1] → ...

When 3 sensors are enabled, the sequence will be extended to include the 6 corresponding magnetometer samples.

#### Bypass Mode

In Bypass mode (set in FIFO\_CTRL), the FIFO is not operational and, therefore, remains empty. Sampled data from the gyroscope and/or Accelerometer are stored directly in the Sensor Data Output Registers. When new data is available, the old data is over-written.

#### FIFO Mode

In FIFO mode, data from the sensors are stored in the FIFO. The watermark interrupt, if enabled in FIFO\_CTRL, is triggered when the FIFO is filled to the level specified by the value of wtm<1:0> in the FIFO\_CTRL register. The FIFO continues filling until it is full. When full, the FIFO stops collecting data from the input channels. Data collection restarts when FIFO is emptied.

#### Streaming Mode

In Streaming mode (set in FIFO\_CTRL), data from the gyroscope and accelerometer are stored in the FIFO. A watermark interrupt can be enabled and set as in FIFO mode. The FIFO continues filling until full. In this mode, the FIFO acts as a circular buffer, when full, the FIFO discards the older data as the new data arrives. Programmable watermark level events can be enabled to generate dedicated interrupts on the DRDY/INT2 pin (configured through the FIFO\_CTRL register).

## 8.2 FIFO Register Description

Table 32. FIFO Registers Description

Register Name			
<b>FIFO_WTM_TH</b>		<b>FIFO Watermark Threshold. Register Address: 19 (0x13)</b>	
Bits	Name	Default	Description
7:0	FIFO_wtm_th	1'b0	Set watermark level, in ODRs.
<b>FIFO_CTRL</b>		<b>Configure FIFO. Register Address: 20 (0x14)</b>	
Bits	Name	Default	Description
7	FIFO_rd_mode	1'b0	0: Disable FIFO read via FIFO_DATA register. 1: FIFO read via FIFO_DATA register is enabled. This bit is automatically set by the CTRL9 command to request the FIFO.
6:4	Reserved	3'b0	Reserved
3:2	size<1:0>	2'b0	Set FIFO size. (See <b>Error! Reference source not found.</b> for more details.) 00 – Set FIFO size at 16 samples for each enabled sensor 01 – Set FIFO size at 32 samples for each enabled sensor 10 – Set FIFO size at 64 samples for each enabled sensor 11 – Set FIFO size at 128 samples for each enabled sensor (up to 2 sensors enabled only)
1:0	mode<1:0>	1'b0	Set FIFO Mode. 00 – Bypass (FIFO disable). 01 – FIFO. 10 – Streaming. 11 – Not Used
<b>FIFO_SMPL_CNT</b>		<b>FIFO Sample Count. Register Address: 21 (0x15)</b>	
Bits	Name	Default	Description
7:0	fifo_smpl_cnt_lsb	8'h00	The LS 8 bits of FIFO sample count, in bytes.
<b>FIFO_STATUS</b>		<b>FIFO Status. Register Address: 22 (0x16)</b>	
Bits	Name	Default	Description
7	fifo_full	1'b0	FIFO size has been reached and is full.
6	wtm	1'b0	Watermark level hit.
5	overflow	1'b0	FIFO over-flow condition has occurred. An attempt was made to save new data to the FIFO while it was full.
4	not_empty	1'b0	FIFO not empty.
3:2	reserved	2'b0	
1:0	fifo_smpl_cnt_msb	2'b0	The MS 2 bits of FIFO sample count, in bytes.
<b>FIFO_DATA</b>		<b>FIFO Data Register. Register Address: 23 (0x17)</b>	
Bits	Name	Default	Description
7:0	data<7:0>	8'b0	Read this register to read sensor data out of FIFO.

## 9 Wake on Motion (WoM)

### 9.1 Wake on Motion Introduction

The purpose of the Wake on Motion (WoM) functionality is to allow a system to enter a low power sleep state while the system is static and then to automatically awaken when moved. In this mode the system should use very little power, yet still respond quickly to motion.

It is assumed that the system host processor is responsible for configuring the QMI8658C correctly to place it into Wake on Motion mode, and that the system host processor will reconfigure the QMI8658C as necessary following a WoM interrupt.

Wake on Motion is configured through the CTRL9 command interface (see write-up for CTRL\_CMD\_WRITE\_WOM\_SETTING in Section 5.8.5 CTRL9 Commands in Detail).

Table 33. Registers used for WoM

Register (bits)	Function
CAL1_L (0:7)	WoM Threshold: absolute value in mg (with 1mg/LSB resolution) 0x00 must be used to indicate that WoM mode is disabled
CAL1_H (7:6)	WoM interrupt select 01 – INT2 (with initial value 0) 11 – INT2 (with initial value 1)  00 – INT1 (with initial value 0) 10 – INT1 (with initial value 1)
CAL1_H (0:5)	Interrupt blanking time (in number of accelerometer samples)

The threshold value is configurable to make the amount of motion required to wake the device controllable by the host application. The special threshold value of 0x00 can be used to disable the WoM mode, returning the interrupt pins to their normal functionality.

The interrupt initial value (1 or 0) and the interrupt pin used for signaling (INT1 or INT2) are selectable to make it easy for system integrators to use the WoM motion mode to wake the host processor from its deepest sleep level. Using the lowest power mode on many microcontrollers requires the use of special wake up pins that may have only a single polarity setting, and thus may not be useable for other special purposes such as timer captures.

The interrupt blanking time is a programmable number of accelerometer samples to ignore when starting WoM mode so that no spurious wake-up events are generated by startup transients.

### 9.2 Accelerometer Configuration

For additional tuning of the WoM responsiveness, the precise configuration of the accelerometer is left to the host. This gives the host processor the ability to program the desired sample rate and full-scale range.

### 9.3 Wake on Motion Event

When a Wake on Motion event is detected the QMI8658C will set bit 2 (WoM) in the STATUS1 register. Reading STATUS1 by the host will clear the WoM bit and will reset the chosen interrupt line (INT1 or INT2, see previous section) to the value given by the WoM interrupt initial value (see previous section).

For each WoM event, the state of the selected interrupt line is toggled. This ensures that while the system is moved, the host processor will receive wakeup interrupts regardless of whether it uses high, low, positive- or negative-edge interrupts.

The QMI8658C stays in WoM mode until commanded to enter a new mode by the host processor.

### 9.4 Configuration Procedure

The host processor is responsible for all configurations necessary to put the QMI8658C into WoM mode. The specific sequence of operations performed by the host processor to enable WoM is shown in Figure 10.

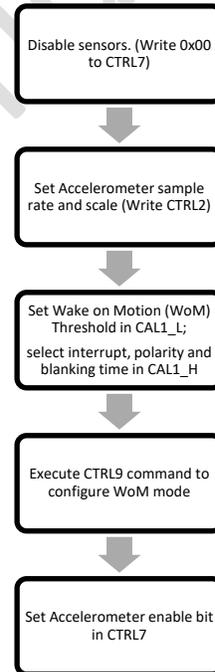


Figure 10. WoM Configuration Commands and Sequence

The WoM bit is cleared upon setting the WoM threshold to a non-zero value, and the selected interrupt pin is configured according to the settings. Special care has been taken that the WoM interrupt does not activate due to any transients when the accelerometer is first enabled. An interrupt blanking time is included that prevents such spurious interrupts to propagate.

### 9.5 Wake on Motion Control Registers

The WoM configuration is controlled by values written to the CAL1\_x registers, as shown in Table 33.

### 9.6 Exiting Wake on Motion Mode

To exit WoM mode the host processor must first clear CTRL7 to disable all sensors, and then write a threshold value of 0x0 for the WoM Threshold (see Table 33, Registers used for WoM) and execute the WoM configuration CTRL9 command (see write-up for CTRL\_CMD\_WRITE\_WOM\_SETTING in Section 5.8.5 CTRL9 Commands in Detail). On doing this the interrupt pins will return to their normal function. After zeroing the WoM Threshold the host processor may proceed to reconfigure the QMI8658C as normal, as in the case following a reset event.

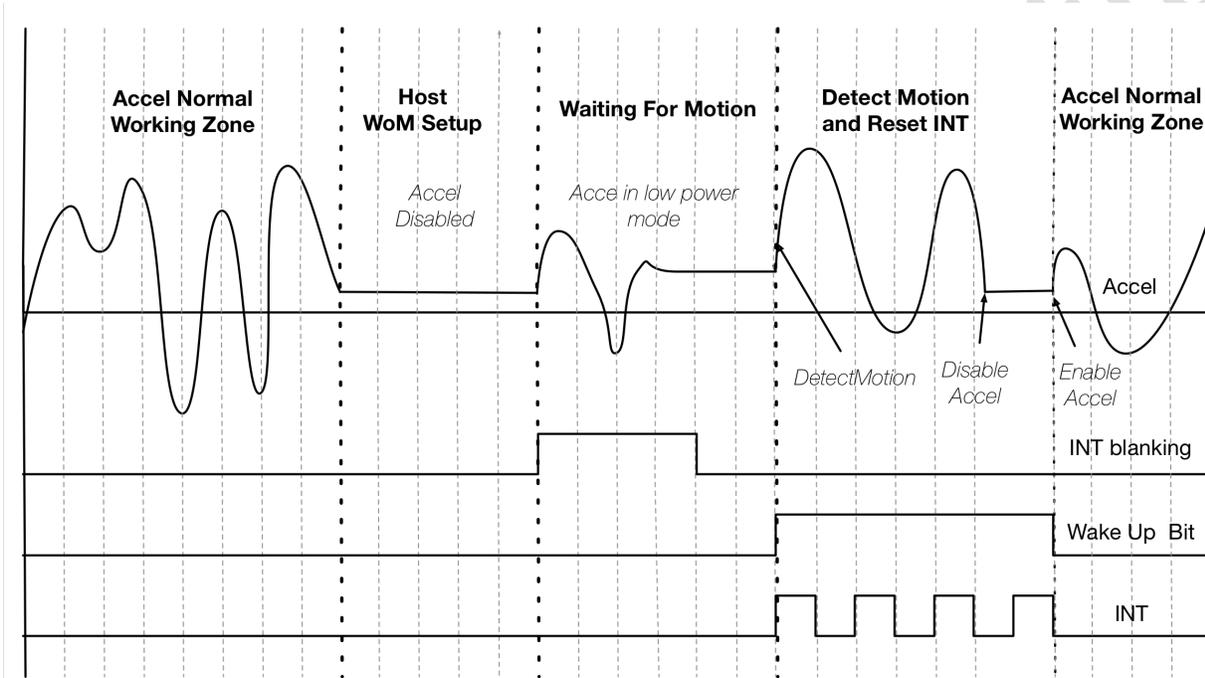


Figure 11. WoM Example Diagram

## 10 Performing Device Self Test

### 10.1 Accelerometer Self Test

The accelerometer Self Test is used to determine if the accelerometer is functional and working within acceptable parameters. The accelerometer Self Test methodology is TBD.

- 1.

### 10.2 Gyroscope Self Test

The gyroscope Self Test is used to determine if the gyroscope is functional and working within acceptable parameters. The gyroscope Self Test methodology is TBD.

## 11 Magnetometer Setup

### 11.1 Magnetometer Description

The QMI8658C provides an I<sup>2</sup>C master interface (I2CM) to connect with an external magnetometer. Currently the QMI8658C can support the following magnetometers: AK09915C, AK09918CZ, and QMC6308. To simplify data acquisition between the magnetometer and the IMU, the QMI8658C can time align the magnetometer samples with the gyroscope and accelerometer samples.

## 12 Host Serial Interface

QMI8658C Host Serial Interface supports MIPI I3C, I<sup>2</sup>C and SPI slave interfaces. For SPI, it supports both 3-wire and 4-wire modes. The basic timing characteristics for the interface are described below. Through the QMI8658C Host Serial Interface, the host can access, setup and control the QMI8658C Configuration Registers (see Table 24).

### 12.1 Serial Peripheral Interface (SPI)

QMI8658C supports both 3-wire and 4-wire modes in the SPI slave interface. The SPI 4-wire mode uses two control lines (CS, SPC) and two data lines (SDI, SDO). The SPI 3-wire mode uses the same control lines and one bi-directional data line (SDIO). The SDI/SDIO pin is used for both 3- and 4-wire modes and is configured based on the mode selected. The SPI interface has been validated at 15 MHz and the timing parameters are measured at that interface frequency.

SPI transactions can be done in either Mode 0 (CPOL=0, CPHA=0) or Mode 3 (CPOL=1, CPHA=1). The interface automatically detects which mode is in use and configures clocking accordingly.

SPI 3- or 4-wire modes are configured by writing to bit-7 of CTRL1 register. 3-wire mode is selected when bit-7 is 1. The default configuration is 4-wire mode, i.e. bit-7 of CTRL1 is 0.

Figure 12 shows the SPI address and data formats.

#### SPI Features

- Data is latched on the rising edge of the clock
- Data should change on falling edge of clock
- Maximum frequency is 15 MHz
- Data is delivered MSB first
- Support single read/writes and multi cycle (Burst) read/writes. **NOTE:** burst writes to Configuration registers are NOT supported. These registers should be written in single cycle mode only.
- Supports 6-bit Address format and 8-bit data format

#### Address Format

MSB							LSB
Read	A6	A5	A4	A3	A2	A1	A0

Read – indicates read (1) or write (0) transaction relative to the SPI master

#### Data Format

MSB							LSB
D7	D6	D5	D4	D3	D2	D1	D0

Figure 12. SPI Address and Data Format

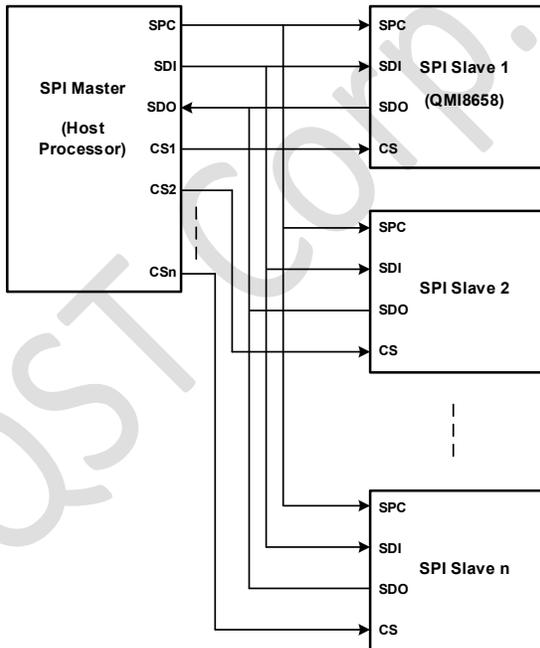


Figure 13. Typical SPI 4-Wire Multi-Slave

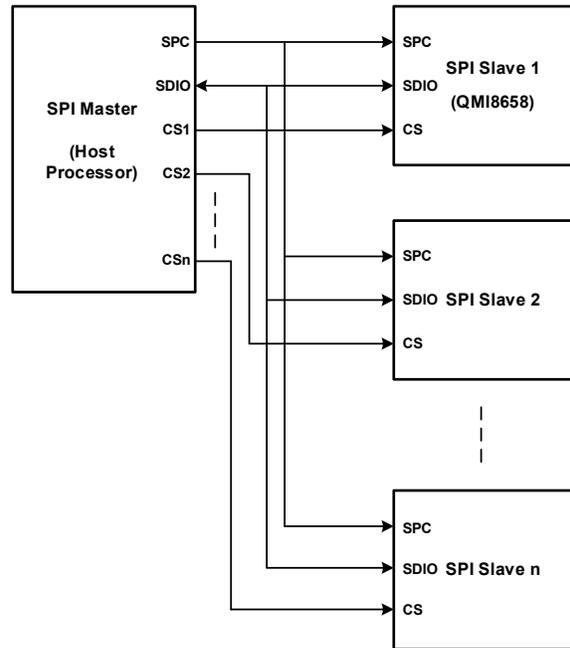


Figure 14. Typical SPI 3-Wire Multi-Slave

In a typical SPI Master/Slave configuration the SPI master shares the SPI clock (SPC), the serial data input (SDI), and the Serial Data Output (SDO) with all the connected SPI slave devices. Unique Chip Select (CS) lines connect each SPI slave to the master.

replaced by the bi-directional SDIO line. The SDIO line is driven by the master with both address and data when it is configured for write mode. During read mode, the SDIO line is driven by the master with the address, and subsequently driven by the “addressed” slave with data.

Figure 13 and Figure 14 show typical multi-slave 4- and 3-wire configurations. The primary difference between the two configurations is that the SDI and SDO lines are

Figure 15 and Figure 16 illustrate the waveforms for both 4-wire and 3-wire SPI read and write transactions. Note that CS is active during the entire transaction.

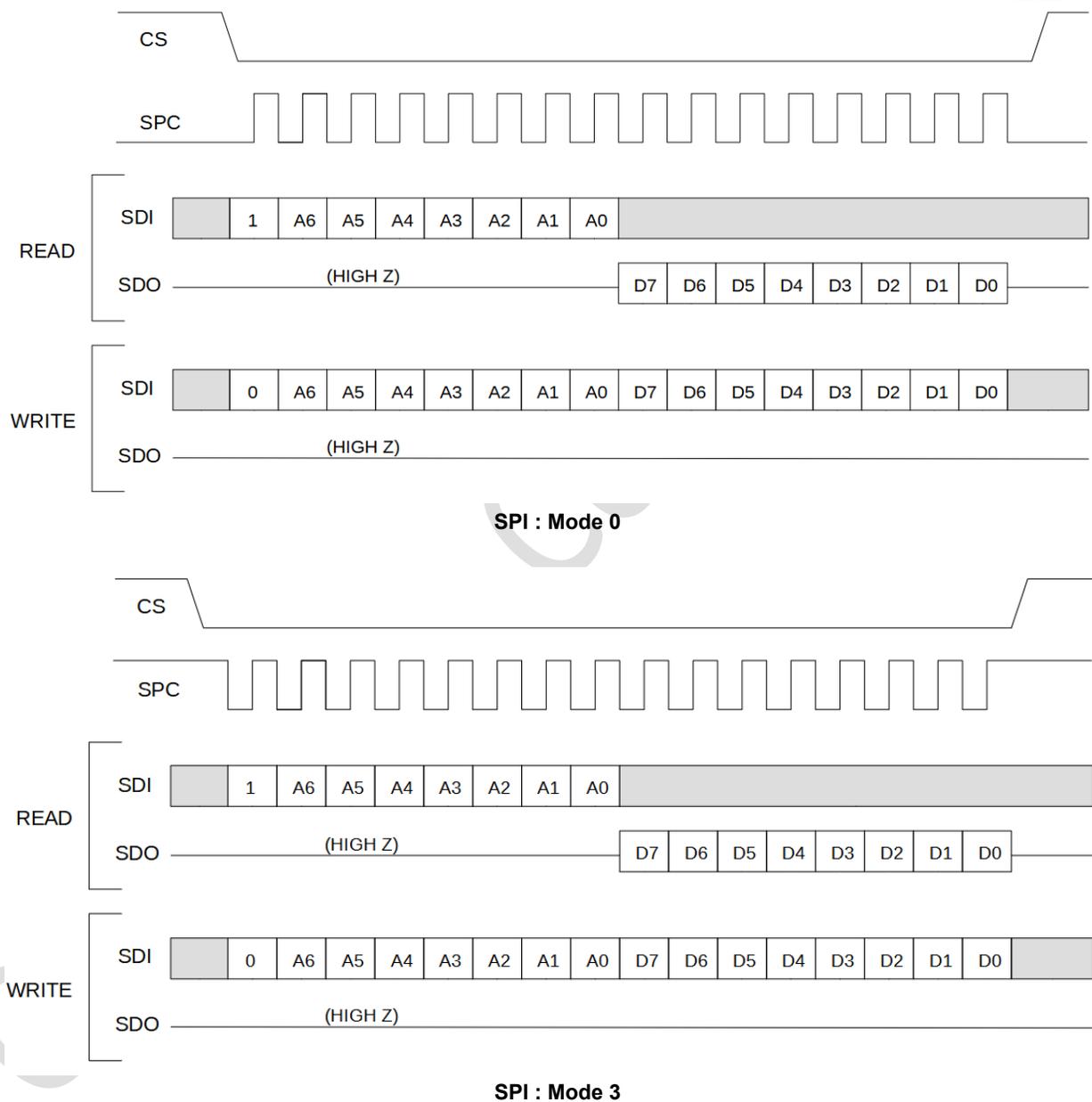


Figure 15. SPI 4-Wire Single Byte Read and Write (Mode 0 and Mode 3)

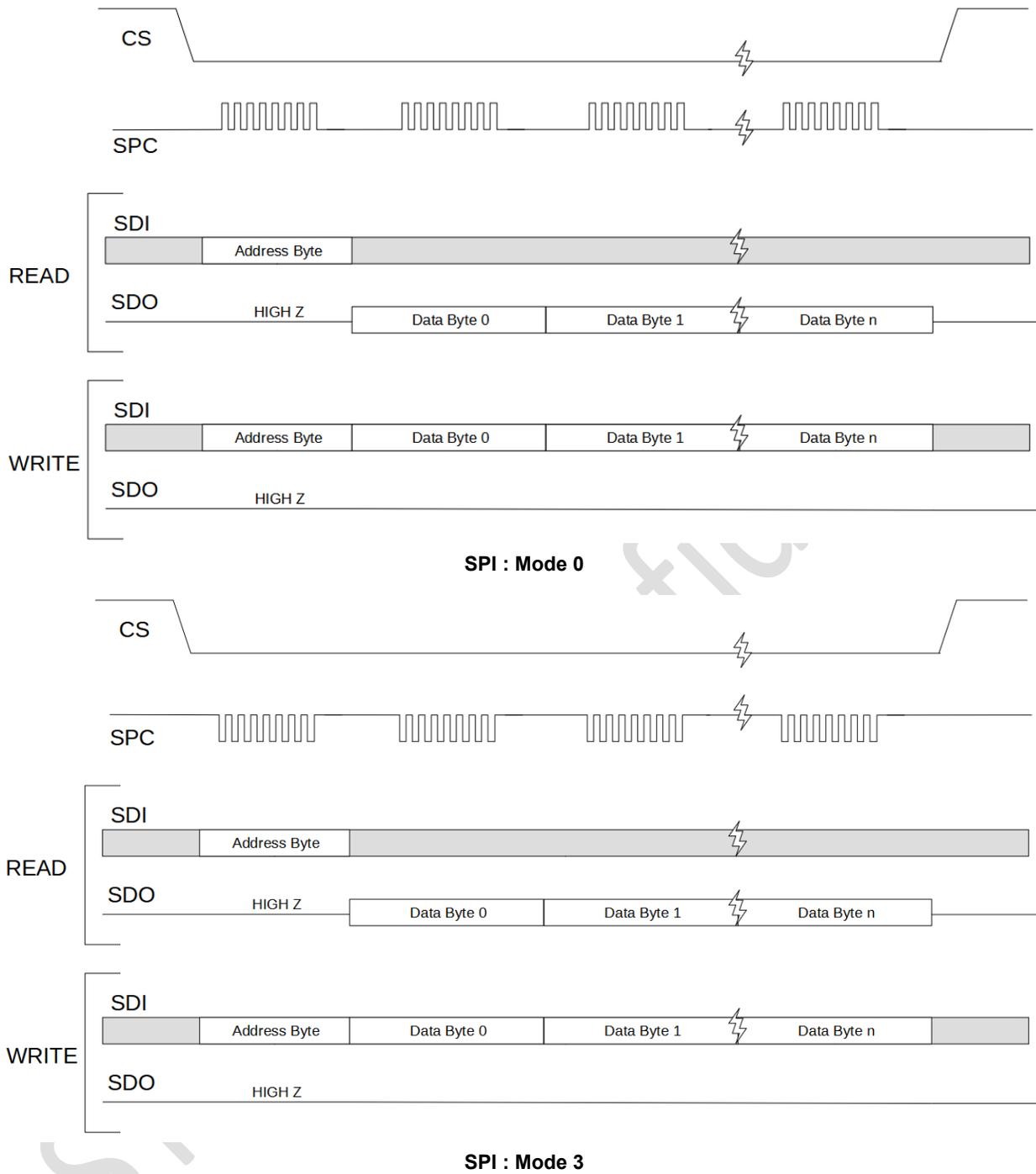


Figure 16. SPI 4-Wire Multi-Byte Read and Write Transactions

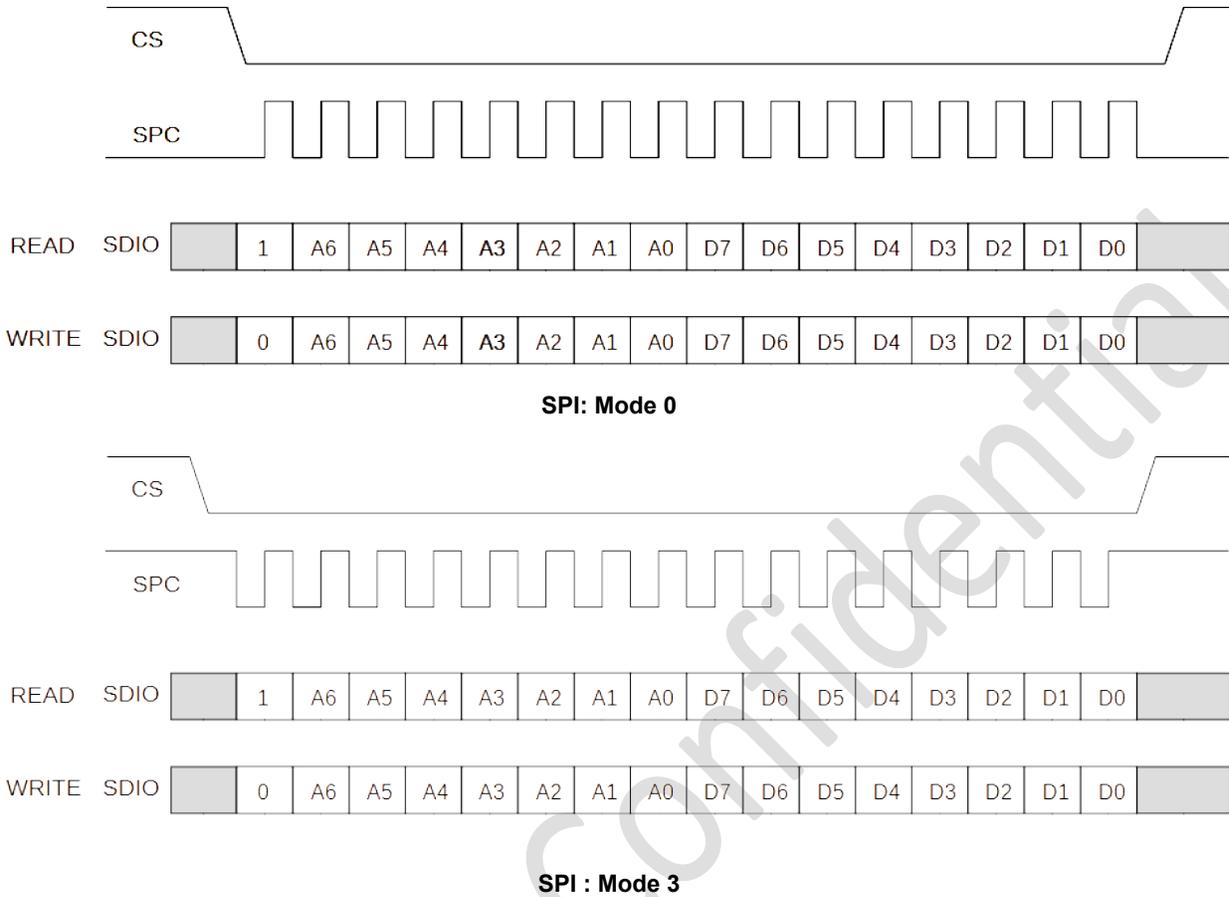


Figure 17. SPI 3-Wire Single Byte Read and Write Transactions

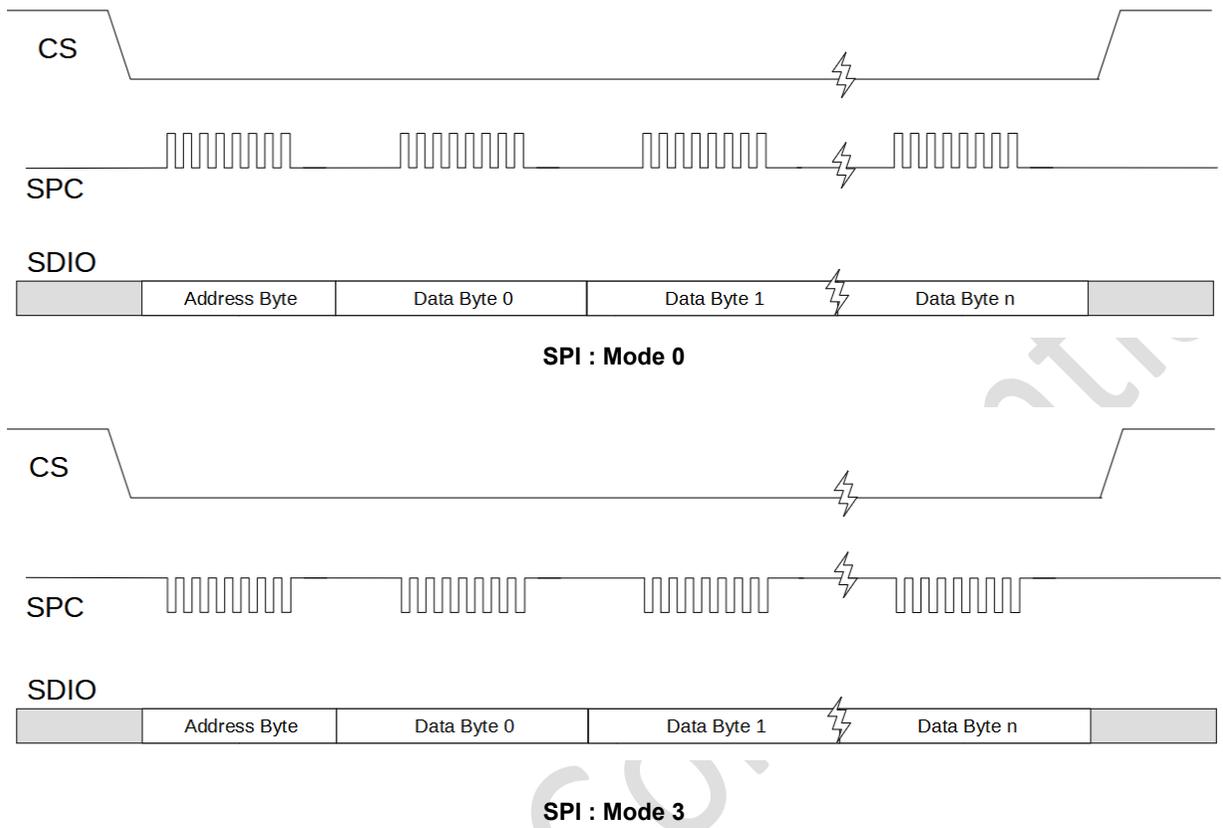


Figure 18. SPI 3-Wire Multi-Byte Read and Write Transactions

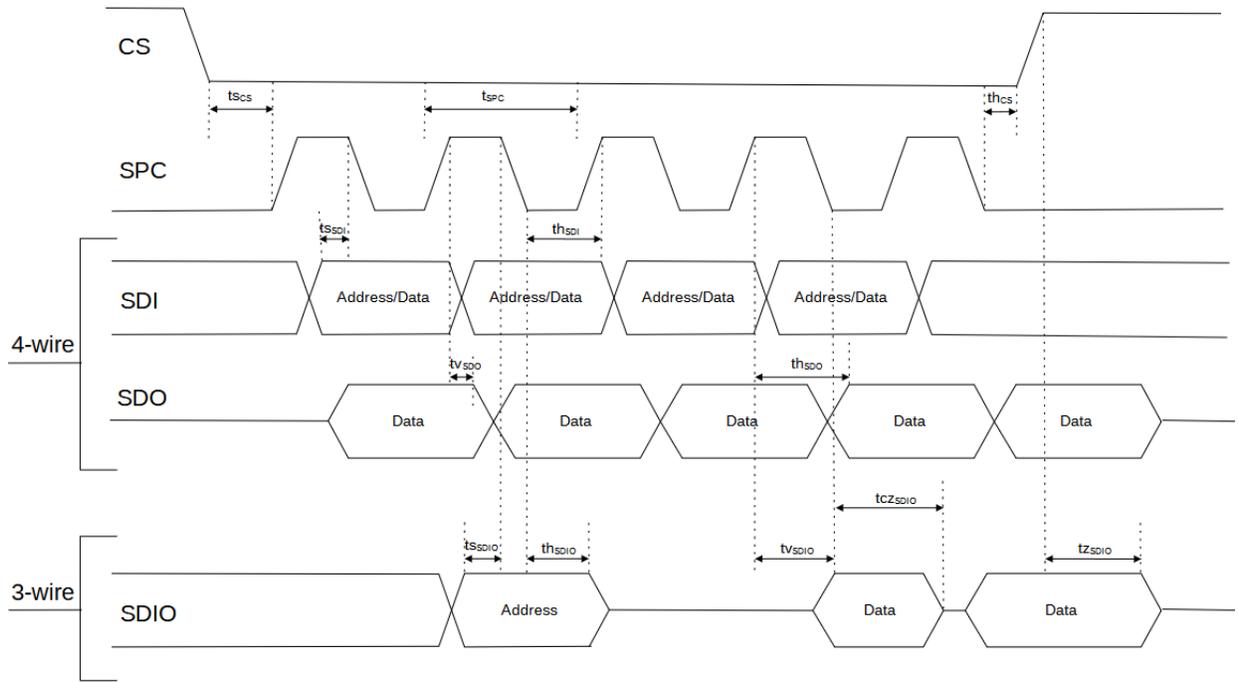
### 12.1.1 SPI Timing Characteristics

The typical operating conditions for the SPI interface are provided in Table 34

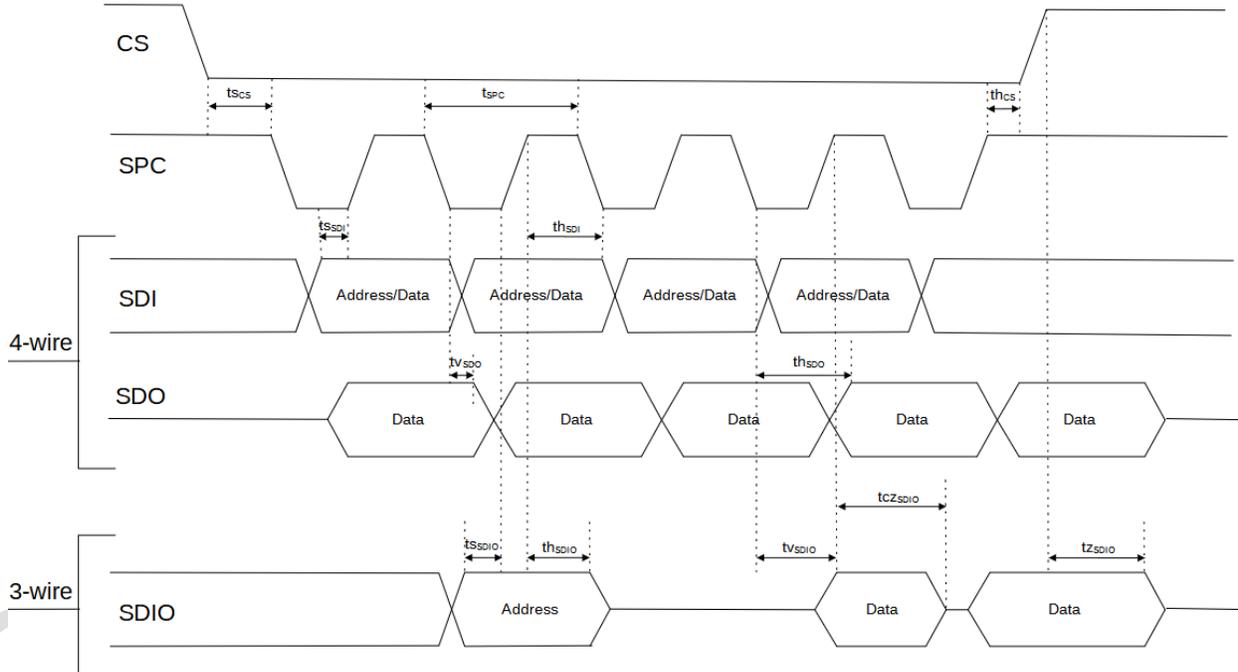
VDDIO = 1.8 V, T = 25°C unless otherwise noted.

Table 34. SPI Interface Timing Characteristics

Symbol	Parameter	Min.	Max.	Unit
t <sub>SPC</sub>	SPI Clock Cycle	66.6		ns
f <sub>SPC</sub>	SPI Clock Frequency		15	MHz
t <sub>SCS</sub>	CS Setup Time	6		ns
t <sub>HCS</sub>	CS Hold Time	8		ns
t <sub>SDI</sub>	SDI Input Setup Time	5		ns
t <sub>HSDI</sub>	SDI Input Hold Time	15		ns
t <sub>VSDO</sub>	SDO Time for Valid Output		50	ns
t <sub>HSDO</sub>	SDO Hold Time for Output	9		ns
t <sub>DSDO</sub>	SDO Disable Time for Output		50	ns
t <sub>SDIO</sub>	SDIO Address Setup Time	5		ns
t <sub>HSDIO</sub>	SDIO Address Hold Time	15		ns
t <sub>VSDIO</sub>	SDIO Time for Valid Data		50	ns
t <sub>CZSDIO</sub>	SDIO Time from SPC to High Z		50	ns
t <sub>ZSDIO</sub>	SDIO Time from CS to High Z		50	ns



SPI : Mode 0



SPI : Mode 3

Figure 19. Timing Characteristics for SPI 3- and 4-Wire Interfaces

## 12.2 I<sup>2</sup>C Interface

Table 35 provides the I<sup>2</sup>C interface timing characteristics while Figure 20 and Figure 21 illustrate the I<sup>2</sup>C timing for both fast and standard modes, respectively.

During the slave device selection phase, the I<sup>2</sup>C master supplies the 7-bit I<sup>2</sup>C slave device address to enable the QMI8658C. The 7-bit device address for the QMI8658C is 0x6a (0b1101010) if SA0 is left unconnected, internally there is a weak pull-down of 200 kΩ thereby selecting bit-0=0. In case of a slave device ID conflict, SA0 may be used to change bit-0 of the device address. When SA0 is pulled up externally, the 7-bit device address becomes 0x6b (0b1101011).

During the slave register address phase bit-7 of the address is used to enable auto-increment of the target address. When bit-7 is set to 1 the target address is automatically incremented by one.

For additional technical details about the I<sup>2</sup>C standard, such as pull-up resistor sizing the user is referred to “UM10204 I<sup>2</sup>C-bus specification and user manual,” published by NXP B.V.

Table 35. I<sup>2</sup>C Timing Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f <sub>SCL</sub>	SCL Clock Frequency	Standard Mode			100	kHz
		Fast Mode			400	
t <sub>BUF</sub>	Bus-Free Time between STOP and START Conditions	Standard Mode		4700		ns
		Fast Mode		1300		
t <sub>HD,STA</sub>	START or Repeated START Hold Time	Standard Mode		4000		ns
		Fast Mode		600		
t <sub>LOW</sub>	SCL LOW Period	Standard Mode		4700		ns
		Fast Mode		1300		
t <sub>HIGH</sub>	SCL HIGH Period	Standard Mode		4000		ns
		Fast Mode		600		
t <sub>SU,STA</sub>	Repeated START Setup Time	Standard Mode		4700		ns
		Fast Mode		600		
t <sub>SU,DAT</sub>	Data Setup Time	Standard Mode		250		ns
		Fast Mode		100		
t <sub>HD,DAT</sub>	Data Hold Time	Standard Mode	0		3450	ns
		Fast Mode	0		900	
t <sub>RCL</sub> , t <sub>r</sub>	SCL Rise Time	Standard Mode			1000	ns
		Fast Mode		20 + 0.1 * C <sub>B</sub> <sup>(14)</sup>	300	
t <sub>FCL</sub>	SCL Fall Time	Standard Mode			300	ns
		Fast Mode		20 + 0.1 * C <sub>B</sub> <sup>(14)</sup>	300	
t <sub>RDA</sub> , t <sub>RCL1</sub>	SDA Rise Time. Rise Time of SCL after a Repeated START Condition and after ACK Bit	Standard Mode			1000	ns
		Fast Mode		20 + 0.1 * C <sub>B</sub> <sup>(14)</sup>	300	
t <sub>FDA</sub>	SDA Fall Time	Standard Mode			300	ns
		Fast Mode		20 + 0.1 * C <sub>B</sub> <sup>(14)</sup>	300	
t <sub>SU,STO</sub>	Stop Condition Setup Time	Standard Mode		4000		ns
		Fast Mode		600		

**Note:**

14. C<sub>B</sub> is the bus capacitance.

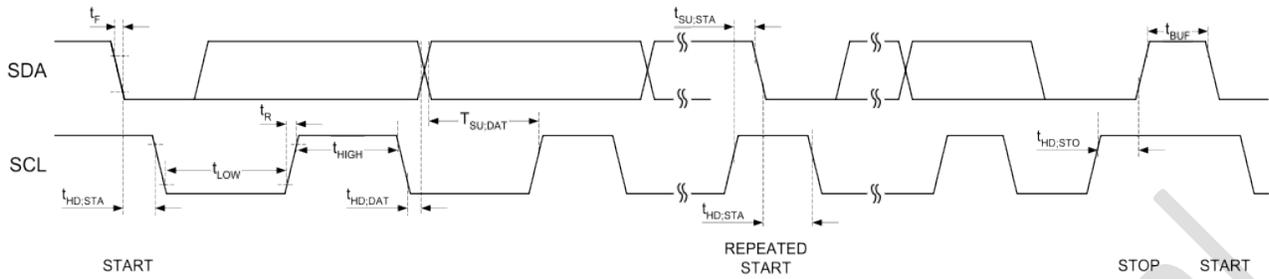
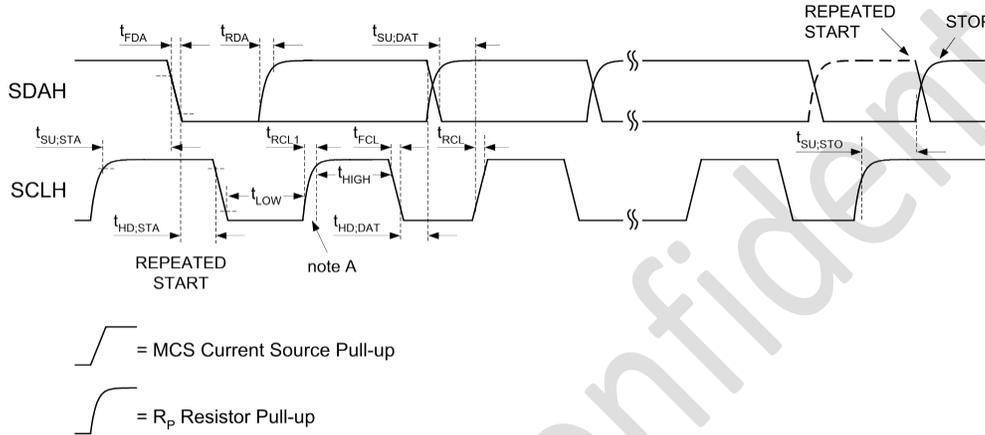


Figure 20. I<sup>2</sup>C Standard Mode Interface Timing



Note A: First rising edge of SCLH after Repeated Start and after each ACK bit.

Figure 21. I<sup>2</sup>C Fast Mode Interface Timing

### 12.3 MIPI I3C Interface

The QMI8658C is compliant with the MIPI Alliance Specification for I3C, version 1.0.

# 13 Package and Handling

## 13.1 Package Drawing

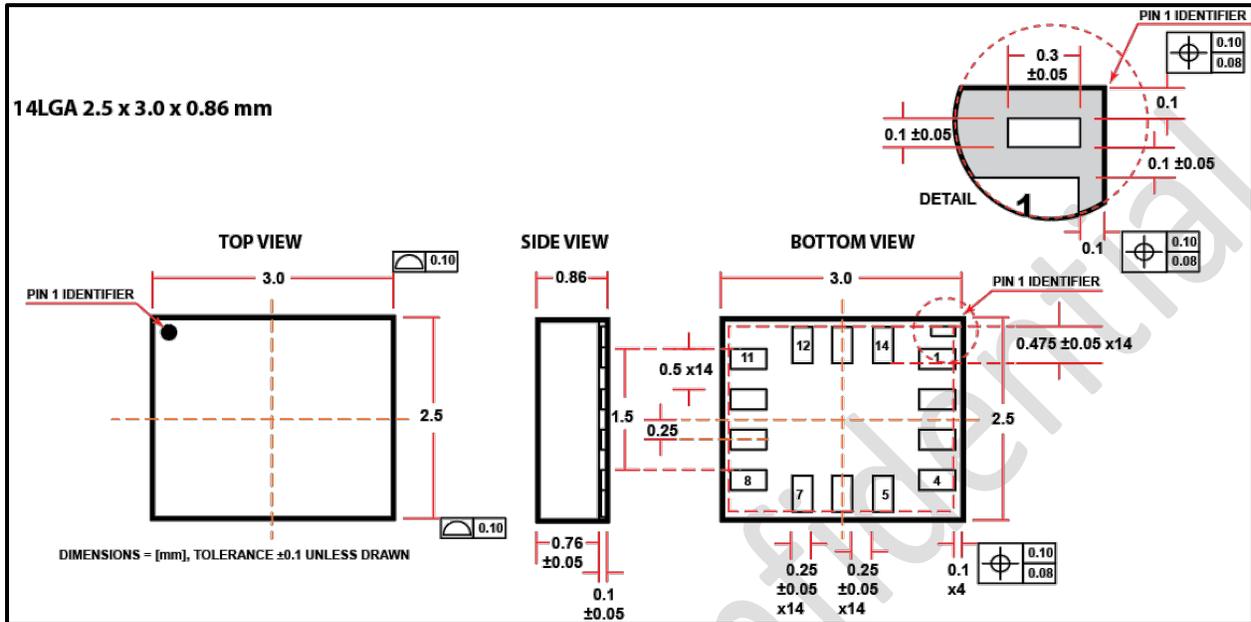
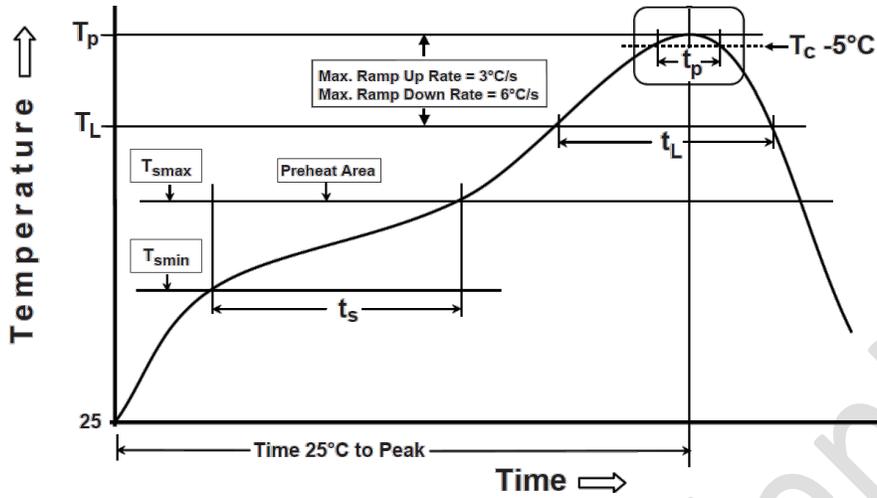


Figure 22. 14 Pin LGA 2.5 x 3.0 x 0.86 mm Package

### 13.2 Reflow Specification



**Note:**  
15. Figure from JEDEC J-STD-020

Profile Feature	Pb-Free Assembly Profile
Temperature Min. ( $T_{smin}$ )	150°C
Temperature Max. ( $T_{smax}$ )	200°C
Time ( $t_s$ ) from ( $T_{smin}$ to $T_{smax}$ )	60-120 seconds
Ramp-up Rate ( $T_L$ to $T_P$ )	3°C/second max.
Liquidous Temperature ( $T_L$ )	217°C
Time ( $t_L$ ) Maintained above ( $T_L$ )	60-150 seconds
Peak Body Package Temperature ( $T_P$ )	260°C +0°C / -5°C
Time ( $t_p$ ) within 5°C of 260°C	30 seconds
Ramp-down Rate ( $T_P$ to $T_L$ )	6°C/second max.
Time 25°C to Peak Temperature	8 minutes max.

Figure 23. Reflow Profile

### 13.3 Storage Specifications

QMI8658C storage specification conforms to IPC/JEDEC J-STD-020D.01 Moisture Sensitivity Level (MSL) 3. Floor life after opening the moisture-sealed bag is 168 hours with storage conditions: Temperature: ambient to  $\leq 30^\circ\text{C}$  and Relative Humidity: 60%RH.

## 14 Document Information

### 14.1 Revision History

Revision	Revision Date	Description
0.4	April 22, 2020	Initial release of Advance Information datasheet
0.5	July 7, 2020	Updated CAL Register Addresses, CTRL9 Commands and Descriptions, Current Consumption, Accelerometer and Gyroscope Filter Characteristics, Low Power Mode ODR, Wake on Motion, Magnetometer Sensors supported
0.6	Jan 13, 2021	Updated SPI description and diagrams, SPI modes, product performance specifications, and register map and descriptions

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