QMI8658C DATASHEET

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QMI8658C
Wide Bandwidth 6D Inertial Measurement Unit with Sensor Fusion

Features

- Low-noise, wide-bandwidth IMU (accelerometer plus gyroscope) for consumer applications such as toys, drones, e-bikes and scooters, and motion-based remote controls and air mice
- Low 15 mdps/√Hz gyroscope noise and 200µg/√Hz accelerometer noise
- Host (slave) interface supports MIPI™ I3C, I^{2}C, and 3-wire or 4-wire SPI; auxiliary master I^{2}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 ±3º pitch and roll, ±5º 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
- 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 ±32°/s to ±4096°/s for gyroscope and ±2 g to ±16 g for accelerometer
- Low power modes for effective power management
- 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 ±3° pitch and roll orientation, and a ±5° yaw/heading typical specification.

With board-level gyroscope sensitivity of ±3%, gyroscope noise density of 15 mdps/√Hz, and low latency, the QMI8658C is ideal for consumer applications such as toys, drones, e-bikes and scooters, and motion-based remote controls and air mice.

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

Applications

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

Table of Contents

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	8658	DDDD – Device code
2	0113	YWLL – Y (Year code), W (1-digit, biweekly code), LL (Lot indication)
3	● DA	CR – C (Assembly location), R (Product revision)

Figure 1. Top Mark

1.3 Internal Block Diagram

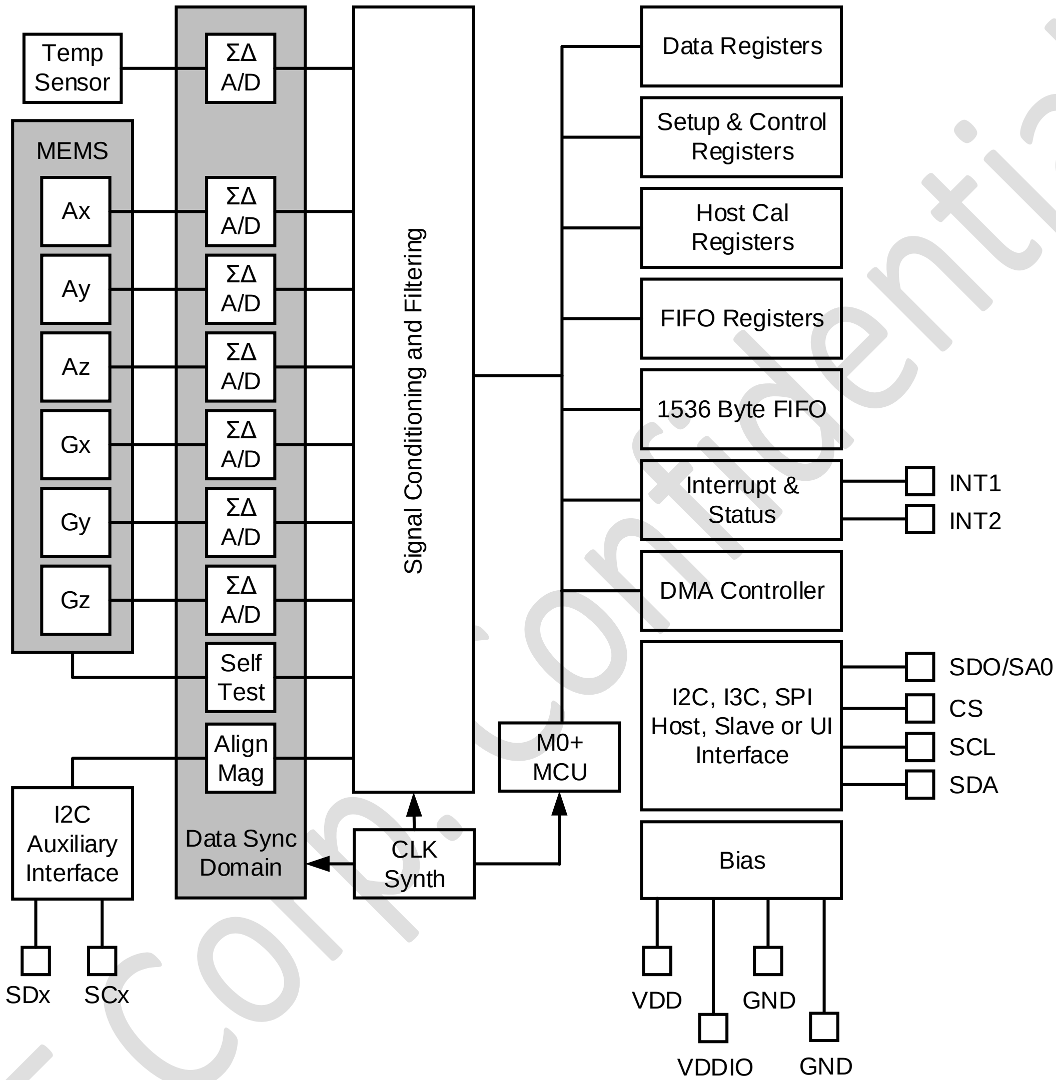


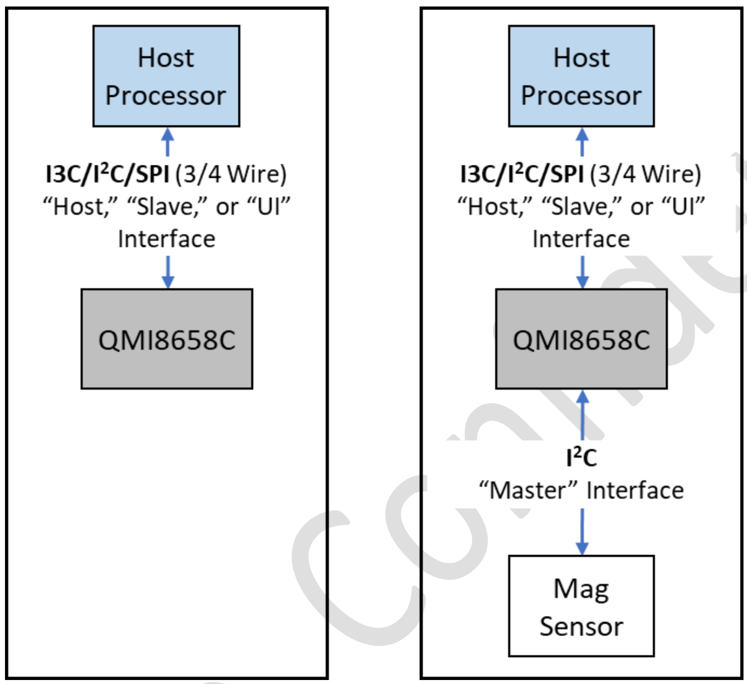
Figure 2. Internal Block Diagram

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^2C, I3C, 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^2C, I3C, and SPI (3-wire or 4-wire modes). However, in Mode 2, the external sensor bus is enabled and the QMI8658C acts as an I^2C 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.

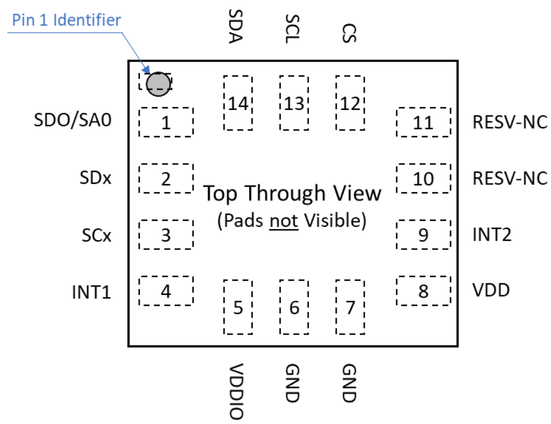


Figure 4. Pins Face Down (Top View)

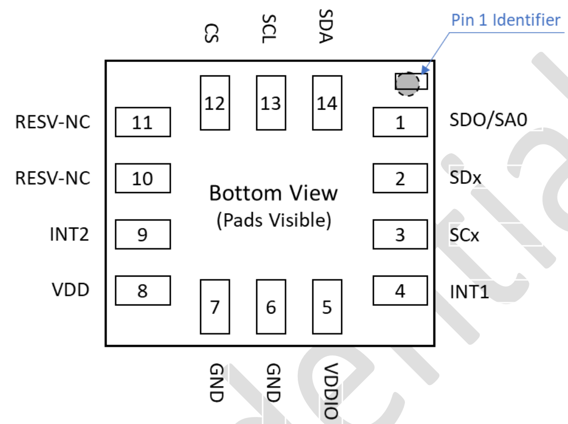


Figure 5. Pins Face Up (Bottom View)

Table 2. **Pin Definitions**

Pin Number	Type	Pin Name	Mode 1 Function (Default Mode)	Mode 2 Function (External Sensor Mode)
1	O	SDO/SA0[1][3]	SPI-UI Data Out (SDO) in SPI-UI 4-Wire Mode. I^2C Slave LSB bit of the device Address (SA0)	
2	IO	SDx	Connect to VDDIO or GND	I^2C Master Serial Data (MSDA)
3	IO	SCx	Connect to VDDIO or GND	I^2C Master Serial Clock (MSCL)
4	O	INT1	Programmable Interrupt 1 for I^2C 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^2C Master external Synchronization Signal (MDRDY)
10	IO	RESV-NC	Reserved. No Connect	
11	I	RESV-NC	Reserved. No Connect	
12	I	CS	I^2C/ I3C /SPI-UI selection Pin. (If 1: I^2C-UI Mode: I^2C/ I3C communication enabled, SPI idle mode) (If 0: SPI-UI mode: I^2C/ I3C disabled)	
13	IO	SCL	SPI-UI Serial Clock (SPC) [2][3]	
14	IO	SDA	I^2C/ I3C-UI Data (SDA) SPI-UI Data In (SDI) [2][3] in 4 wire Mode SPI-UI Data IO (SDIO) [2][3] in 3 Wire Mode	

Notes:
1. This pin has an internal 200 kΩ pull up resistor.
2. In SPI mode (not in I^2C 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_{p1}	Capacitor	Capacitance	100 nF
C_{p2}	Capacitor	Capacitance	100 nF
R_{pu}(4)	Resistor	Resistance	10 kΩ

Note:

4. R_{pu} resistors are only needed when the Host Serial Interface is configured for I^2C (see I^2C 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^2C Modes are all possible. If a pull-up resistor is used on SA0, an alternate slave address is used for I^2C. SPI and I3C modes will be unaltered with the use of pull-up resistors for I^2C. Additionally, a suitable pull up resistance (R_{pu}) value should be selected, accounting for the tradeoff between current consumption and rise time.

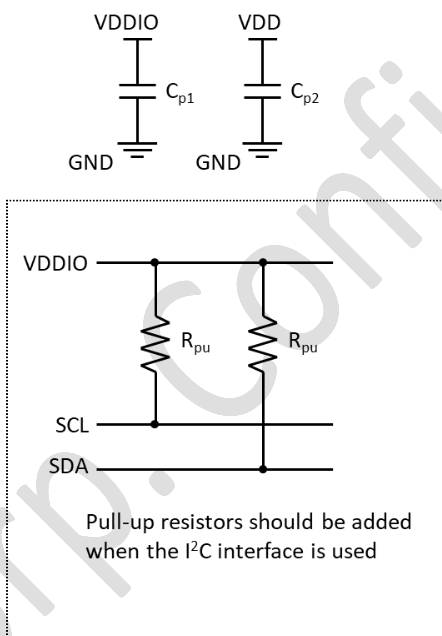


Figure 6. Typical Electrical Connections

2 QMI8658C Architecture

QMI8658C is a high-performance IMU which works included sensor fusion software (XKF3) that allows the device to achieve orientation accuracies of ±3º for pitch and roll and ±5º 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 with minimal latency.

An internal block diagram is shown in Figure 2. The MEMS elements are amplified and converted by ΣΔ 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.

2.1 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 QMI8658A/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
- 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

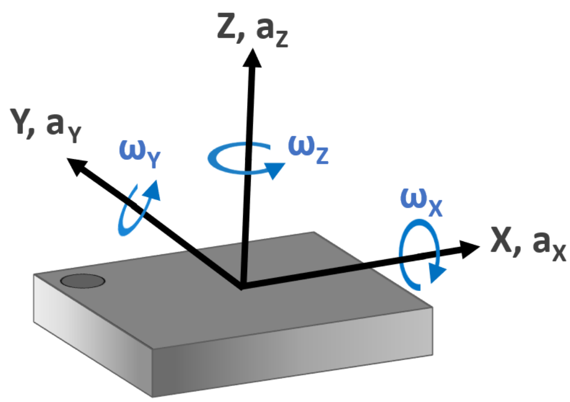


Figure 7. Chip Orientation Coordinate System

2.2 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 (ω_x, ω_y, ω_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_{STG}	Storage Temperature		-40	+125	°C
T_{Pmax}	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_g[5]	Acceleration g for 0.2 ms (Un-powered)			10,000	g
ESD[6]	Electrostatic Discharge Protection Level	Human Body Model per JES001-2014	±2000		V
		Charged Device Model per JESD22-C101	±500		

Notes:

5. △This is a mechanical shock (g) sensitive device. Proper handling is required to prevent damage to the part.
6. 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_{IL}	Digital Low Level Input Voltage			0.3 *VDDIO	V
V_{IH}	Digital High Level Input Voltage	0.7 *VDDIO			V
V_{OL}	Digital Low Level Output Voltage			0.1 *VDDIO	V
V_{OH}	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	Requires use of XKF3 software library on host processor.

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	±1		%	
	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[7]	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	±32 dps	1024	LSB/dps	16-Bit Output
		±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[8]	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 = t1 8
	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 Range and Scale**

Subsystem	Parameter	Typical		Unit	Comments
		Scale Setting	**Sensitivity**		
Typical Sensor Mode	Magnetometer Sensitivity Scale Factor	±32 gauss	1,024	LSB/gauss	16 Bit Output

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[9]	4000[9]	2000[9]	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[10]**

Mode	High-Resolution									Low-Power				Unit
ODR	8000[11]	4000[11]	2000[11]	1000	500	250	125	62.5	31.25	128	21	11	3	
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	Hz
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**
ODR	8000	4000	2000	1000	500	250	125	62.5	31.25	Hz
Bandwidth (Default)	4000	2000	1000	500	250	125	62.5	31.3	15.6	
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	
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	
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	
Bandwidth with Low-Pass Filter Enabled Mode 11 (14.0% of ODR)	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_{SPC}	Host SPI Interface Speed			15		MHz
f_{SCL}	Host I^{2}C Interface Speed	Standard Mode		100		kHz
		Fast Mode		400		
f_{SCL2}	Master I^{2}C Interface Speed(12)	Standard Mode		25		kHz
		Fast Mode		300		
f_{SCL3}	Host I3C Interface Speed	Standard Data Rate (SDR)		12.5		MHz

Note:

12. When only accelerometer is enabled, I^{2}C master operates at 25 kHz. When gyroscope is enabled, I^{2}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)	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	µA
	Filters Enabled (aLPF=1)	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	

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)	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	µA
	Filters Enabled (gLPF=1)	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	

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)	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	µA
	Filters Enabled (aLPF=1; gLPF=1)	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	

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 truncated 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 18.* The HOST should synchronize to the interrupt, INT2, signal to get valid temperature readings.

Table 17. **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^{2}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 18 for UI Interface: contain all data for 9D sensors to be accessed from the UI interface – either I^{2}C or SPI.

Table 18. **UI Register Overview**

Name	Type	Register Address			Default	Comment
		Dec	Hex	Binary	Binary	
General Purpose Registers						
WHO_AM_I	r	0	00	00000000	00000101	Device Identifier
REVISION_ID	r	1	01	00000001	01101000	Device Revision ID
Setup and Control Registers						
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	Reserved: Not Used
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
Host Controlled Calibration Registers (See CTRL9, Usage is Optional)						
CAL1_L	rw	11	0B	00001011	00000000	Calibration Register CAL1_L – lower 8 bits. CAL1_H – upper 8 bits.
CAL1_H	rw	12	0C	00001100	00000000	
CAL2_L	rw	13	0D	00001101	00000000	Calibration Register CAL2_L – lower 8 bits. CAL2_H – upper 8 bits.
CAL2_H	rw	14	0E	00001110	00000000	
CAL3_L	rw	15	0F	00001111	00000000	Calibration Register CAL3_L – lower 8 bits. CAL3_H – upper 8 bits.
CAL3_H	rw	16	10	00010000	00000000	
CAL4_L	rw	17	11	00010001	00000000	Calibration Register CAL4_L – lower 8 bits. CAL4_H – upper 8 bits.
CAL4_H	rw	18	12	00010010	00000000	
FIFO Registers						
FIFO_CTRL	rw	19	13	00010011	00000000	FIFO Setup
FIFO_DATA	r	20	14	00010100	00000000	FIFO Data
FIFO_STATUS	r	21	15	00010101	00000000	FIFO Status

Status Registers						
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).
I2CM_STATUS	r	110	6E	01101110	00000000	I2C Master Status.
Timestamp Register						
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	31	00110010	00000000	
Data Output Registers (16 bits 2's Complement Except Self-Test Sensor Data, AE-CLIP and AE_OVFLOW)						
TEMP_L	r	51	33	00110011	00000000	Temperature Output Data TEMP_L – lower 8 bits. TEMP_H – upper 8 bits
TEMP_H	r	52	34	00110100	00000000	
AX_L	r	53	35	00110101	00000000	X-axis Acceleration AX_L – lower 8 bits. AX_H – upper 8 bits
AX_H	r	54	36	00110110	00000000	
AY_L	r	55	37	00110111	00000000	Y-axis Acceleration AY_L – lower 8 bits. AY_H – upper 8 bits
AY_H	r	56	38	00111000	00000000	
AZ_L	r	57	39	00111001	00000000	Z-axis Acceleration AZ_L – lower 8 bits. AZ_H – upper 8 bits
AZ_H	r	58	3A	00111010	00000000	
GX_L	r	59	3B	00111011	00000000	X-axis Angular Rate GX_L – lower 8 bits. GX_H – upper 8 bits
GX_H	r	60	3C	00111100	00000000	
GY_L	r	61	3D	00111101	00000000	Y-axis Angular Rate GY_L – lower 8 bits. GY_H – upper 8 bits
GY_H	r	62	3E	00111110	00000000	
GZ_L	r	63	3F	00111111	00000000	Z-axis Angular Rate GZ_L – lower 8 bits. GZ_H – upper 8 bits
GZ_H	r	64	40	01000000	00000000	
MX_L	r	65	41	01000001	00000000	X-axis Magnetic Field MX_L – lower 8 bits. MX_H – upper 8 bits
MX_H	r	66	42	01000010	00000000	
MY_L	r	67	43	01000011	00000000	Y-axis Magnetic Field MY_L – lower 8 bits. MY_H – upper 8 bits
MY_H	r	68	44	01000100	00000000	
MZ_L	r	69	45	01000101	00000000	Z-axis Magnetic Field MZ_L – lower 8 bits. MZ_H – upper 8 bits
MZ_H	r	70	46	01000110	00000000	
Reset Register						
RESET	w	118	76		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 19 summarizes these pertinent registers.

Table 19. **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 Accelerometer, Gyroscope and Magnetometer Using sEN, 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, Data Overrun, FIFO Ready to be Read, CTRL9 Protocol Bit
Time Stamp	TIMESTAMP[H,M,L]		Sample Time Stamp (Circular Register 0 – 0xFFFFFF)
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 General Purpose Register

Table 20. **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	0x68	Device Revision ID

5.3 Configuration Registers

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

Table 21. **Configuration Registers Description**

<table>
<tr><th colspan="2">Register Name</th><th colspan="2"></th></tr>
<tr><td colspan="2">CTRL1</td><td colspan="2">Serial Interface and Sensor Enable. Register Address: 2 (0x02)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7</td><td>SIM</td><td>1’b0</td><td>0: Enables 4-wire SPI interface
1: Enables 3-wire SPI interface</td></tr>
<tr><td>6</td><td>SPI_AI</td><td>1’b0</td><td>0: Serial interface (SPI or I^2C) address do not auto increment.
1: Serial interface (SPI or I^2C) address auto increment</td></tr>
<tr><td>5</td><td>SPI_BE</td><td>1’b1</td><td>0: SPI read data little endian
1: SPI read data big endian</td></tr>
<tr><td>4:1</td><td>Reserved</td><td>4’b0</td><td>Reserved</td></tr>
<tr><td>0</td><td>SensorDisable</td><td>1’b0</td><td>0: Enables internal 2 MHz oscillator
1: Disables internal 2 MHz oscillator</td></tr>
<tr><td colspan="2">CTRL2</td><td colspan="2">Accelerometer Settings: Address: 3 (0x03)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7</td><td>aST</td><td>1’b0</td><td>Enable Accelerometer Self Test.</td></tr>
<tr><td>6:4</td><td>aFS<2:0></td><td>3’b0</td><td>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</td></tr>
<tr><td>3:0</td><td>aODR<3:0[13]</td><td>4’b0</td><td>Set Accelerometer Output Data Rate (ODR):
<table>
<tr><th>Setting</th><th>ODR Rate (Hz)</th><th>Mode</th><th>Duty Cycle</th></tr>
<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>
</table></td></tr>
</table>

Table 21 Configuration Register Description (Continued)

<table>
<tr><td colspan="2">Register Name</td><td colspan="2"></td></tr>
<tr><td colspan="2">CTRL3</td><td colspan="2">Gyroscope Settings: Address 4 (0x04)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7</td><td>gST</td><td>1'b0</td><td>Enable Gyro Self-Test.</td></tr>
<tr><td>6:4</td><td>gFS<2:0></td><td>3'b0</td><td>Set Gyroscope Full-scale:
000 - ±32 dps
001 - ±64 dps
010 - ±128 dps
011 - ±256 dps
100 - ±512 dps
101 - ±1024 dps
110 - ±2048 dps
111 - ±4096 dps</td></tr>
<tr><td>3:0</td><td>gODR<3:0> [13]</td><td>4'b0</td><td>Set Gyroscope Output Data Rate (ODR):
<table>
<tr><th>Setting</th><th>ODR Rate (Hz)</th><th>Mode</th><th>Duty Cycle</th></tr>
<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>
</table></td></tr>
<tr><td colspan="2">CTRL4</td><td colspan="2">Magnetometer Settings: Address: 5 (0x05)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7</td><td>Reserved</td><td>1'b0</td><td></td></tr>
<tr><td>6:3</td><td>mDEV<3:0></td><td>4'b0</td><td>Designate External Magnetometer Device: (supported devices listed in Section 11).</td></tr>
<tr><td>2:0</td><td>mODR<2:0></td><td>3'b0</td><td>Set Recommended Magnetometer Output Data Rate (ODR):
<table>
<tr><th>Setting</th><th>ODR Rate (Hz)</th></tr>
<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>
</table></td></tr>
</table>

Note:

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

Table 21 Configuration Register Description (Continued)

Register Name			
CTRL5		**Sensor Data Processing Settings. Register Address: 6 (0x06)**	
Bits	**Name**	**Default**	**Description**
7	Reserved	1'b0	
6:5	gLPF_MODE	2'b0	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	aLPF_MODE / BW [Hz]: 00 — 2.62% of ODR 01 — 3.59% of ODR 10 — 5.32% of ODR 11 — 14.0% of ODR
0	aLPF_EN	1'b0	0: Disable Accelerometer Low-Pass Filter. 1: Enable Accelerometer Low-Pass Filter with the mode given by aLPF_MODE.
CTRL7		**Enable Sensors and Configure Data Reads. Register Address: 8 (0x08)**	
Bits	**Name**	**Default**	**Description**
7	syncSmpl	1'b0	0: Disable syncSmpl mode 1: Enable syncSmple mode
6:4	Reserved	3'b0	
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.
CTRL8		**Reserved – Special Settings. Register Address: 9 (0x09)**	
Bits	**Name**	**Default**	**Description**
7:0	Reserved	0x00	Not Used
Register Name			
CTRL9		**Host Commands. Register Address: 10 (0x0A), Referred to: CTRL 9 Functionality (Executing Pre-defined Commands)**	

5.4 FIFO Registers

Table 22. **FIFO Control/Status/Data Registers**

<table>
<tr><th colspan="2">Register Name</th><th colspan="2"></th></tr>
<tr><td colspan="2">FIFO_CTRL</td><td colspan="2">FIFO Control Register Address: 19 (0x13)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7</td><td>FIFO_RD_MODE</td><td>1’b0</td><td>Set this bit to read data out of FIFO via FIFO_DATA register</td></tr>
<tr><td>6</td><td>Reserved</td><td>1’b0</td><td></td></tr>
<tr><td>5:4</td><td>FIFO_WTM</td><td>2’b0</td><td><table>
<tr><td>FIFO_WTM[1:0]</td><td>WaterMark Level</td></tr>
<tr><td>00</td><td>Watermark at 0</td></tr>
<tr><td>01</td><td>Watermark at 1/4 of FIFO size</td></tr>
<tr><td>10</td><td>Watermark at 1/2 of FIFO size</td></tr>
<tr><td>11</td><td>Watermark at 3/4 of FIFO size</td></tr>
</table></td></tr>
<tr><td>3:2</td><td>FIFO_SIZE</td><td>2’b0</td><td><table>
<tr><td>FIFO_SIZE[1:0]</td><td>FIFO Sample Size</td></tr>
<tr><td>00</td><td>16 samples</td></tr>
<tr><td>01</td><td>32 samples</td></tr>
<tr><td>10</td><td>64 samples</td></tr>
<tr><td>11</td><td>128 samples</td></tr>
</table></td></tr>
<tr><td>1:0</td><td>FIFO_MODE</td><td>2’b0</td><td><table>
<tr><td>FIFO_MODE[1:0]</td><td>FIFO Sample Size</td></tr>
<tr><td>00</td><td>Bypass (FIFO disable)</td></tr>
<tr><td>01</td><td>FIFO</td></tr>
<tr><td>10</td><td>Stream</td></tr>
<tr><td>11</td><td>Stream to FIFO. In stream to FIFO mode, once motion/gesture interrupt event happens, content of FIFO will be emptied, pointers reset</td></tr>
</table></td></tr>
<tr><td colspan="2">FIFO_DATA</td><td colspan="2">FIFO DATA Output Register Address: 20 (0x14)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7:0</td><td>FIFO_DATA</td><td>8’b0</td><td>8 bit FIFO data output.</td></tr>
<tr><td colspan="2">FIFO_STATUS</td><td colspan="2">FIFO Status. Register Address 21 (0x15)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7</td><td>Reserved</td><td>1’b0</td><td></td></tr>
<tr><td>6</td><td>FIFO_WTM</td><td>1’b0</td><td>0 -- FIFO Water Mark Level not hit.
1 – FIFO Water Mark Level Hit</td></tr>
<tr><td>5</td><td>FIFO_OVFLOW</td><td>1’b0</td><td>0 – FIFO Over Flow is not presented
1 -- FIFO Over Flow Condition</td></tr>
<tr><td>4</td><td>FIFO_NOT_EMPTY</td><td>1’b0</td><td>0 – FIFO is Empty
1 -- FIFO is not Empty</td></tr>
<tr><td>3:0</td><td>FIFO_FSS</td><td>4’b0</td><td><table>
<tr><td>FIFO_FSS[3:0]</td><td>FIFO Storage Level</td></tr>
<tr><td>0000</td><td>0-7</td></tr>
<tr><td>0001</td><td>8-15</td></tr>
<tr><td>0010</td><td>16-23</td></tr>
<tr><td>0011</td><td>24-31</td></tr>
<tr><td>0100</td><td>32-39</td></tr>
</table></td></tr>
</table>

			0101	40-47
			0110	48-55
			0111	56-63
			1000	64-71
			1001	72-79
			1010	80-87
			1011	88-95
			1100	96-103
			1101	104-111
			1110	112-119
			1111	120-127

5.5 Status and Time Stamp Registers

Table 23. **Status and Time Stamp Registers**

Register Name			
STATUSINT		**Sensor Data Available and Lock Register Address: 45 (0x2D)**	
Bits	**Name**	**Default**	**Description**
7:2	Reserved	5’b0	
1	Locked	1’b0	0: Sensor Data not locked. 1: Sensor Data Locked.
0	Avail	1’b0	0: Sensor Data not available 1: Sensor Data available for reading
STATUS0		**Output Data Status Register Address: 46 (0x2E)**	
Bits	**Name**	Default	**Description**
7	Reserved	1’b0	Reserved
6	mOVRN	1’b0	0: No overrun 1: Magnetometer data overrun. Previous data overwritten before it was read.
5	gOVRN	1’b0	0: No overrun 1: Gyroscope data overrun. Previous data overwritten before it was read.
4	aOVRN	1’b0	0: No overrun 1: Accelerometer data overrun. Previous data overwritten before it was read.
3	Reserved	1’b0	Reserved
2	mDA	1’b0	Valid Magnetometer data available 0: Magnetometer data is NOT Valid 1: Valid Magnetometer data is available at every ODR. If Magnetometer 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.
STATUS1		**Miscellaneous Status. Register Address 47 (0x2F)**	
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.
I2CM_STATUS		**I^2C Master Status, Register Address 110 (0x6E)**	
7:2	Reserved	6’b0	
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^2C read of the next cycle.

0	Stat	1'b0	0: I^{2}C Master Command Transition is not done 1: Indicate I^{2}C Master Command Transition is done.

TIMESTAMP		**3 Bytes Sample Time Stamp – Output Count. Register Address: 48 - 50 (0x30 - 0x32)**	
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 0x0-0xFFFFFF).
7:0	TIMESTAMP_M<15:8>	0x00	
7:0	TIMESTAMP_H<23:16>	0x00	

5.6 Sensor Data Output Registers

Table 24. **Sensor Data Output Registers Description**

Bits	Name	Default	Description
Register Name			
TEMP_[H,L]		**Temp Sensor Output. Register Address: 51 – 52, (0x33 – 0x34)**	
Bits	**Name**	**Default**	**Description**
7:0	TEMP_L	0x00	Temperature output (°C) in two's complement.
7:0	TEMP_H	0x00	
Register Name			
A[X,Y,Z]_[H,L]		**Acceleration Output. Register Address: 53 – 58, (0x35 – 0x3A)**	
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			
G[X,Y.Z]_[H,L]		**Angular Rate Output. Register Address: 59 – 64 (0x3B – 0x40)**	
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			
M[X,Y,Z]_[H,L]		**Magnetometer Output. Register Address: 65 - 70. (0x41 – 0x46)**	
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

5.7 CTRL 9 Functionality (Executing Pre-defined Commands)

5.7.1 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^{2}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**).

5.7.2 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 25. **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

5.7.3 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.

5.7.4 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 26. **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_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^2C 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_ENABLE_EXT_RESET	0x0B	WCtrl9	Enable external soft reset

5.7.5 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_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^2C master, and to execute an I^2C 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_HIGH, CAL1_LOW}
Accel_Delta_Y : {CAL2_HIGH, CAL2_LOW}
Accel_Delta_Z : {CAL3_HIGH, CAL3_LOW}

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_HIGH, CAL1_LOW}
Gyro_Delta_Y : {CAL2_HIGH, CAL2_LOW}
Gyro_Delta_Z : {CAL3_HIGH, CAL3_LOW}

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_ENABLE_EXT_RESET

This CTRL9 Command is issued when the host wants to enable external soft reset by writing 0x0B to CTRL9 register. After enabling, the user needs to write 0x80 to Reset register (address 118) to perform the full system reset.

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.

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 5.7).*

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. 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 21, 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 21, 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.

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.

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

Table 27. **Operating Modes**

Mode	Description	Suggested Configuration
Sensor Modes		
Power-On Default	All sensors off, clock is turned on. The current in this mode is typically 50 µA. 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
Low Power	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 µA. 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
Power-Down	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 µA. The host must initiate this mode by setting sensorDisable=1.	CTRL1 sensorDisable =1 CTRL7 aEN = 0, gEN = 0, mEN = 0, sEN=0. CTRL2 aODR=xxx
Accel Only	Device configured as an accelerometer only.	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR=0xx
Low Power Accel Only	Device configured in low power accelerometer mode.	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR=1xx
Gyro Only	Device configured as a gyroscope only.	CTRL7 aEN =0, gEN =1, mEN =0 CTRL2 aODR=000
Mag Only	Device configured as a magnetometer only.	CTRL7 aEN =0, gEN =0, mEN =1 CTRL2 aODR=000
Accel + Mag	Device configured as an accelerometer and magnetometer combination only. Device can be used as a (stabilized) compass.	CTRL7 aEN =1, gEN =0, mEN =1 CTRL2 aODR=0xx
Accel + Gyro (IMU)	Device configured as an Inertial Measurement Unit, i.e. an accelerometer and gyroscope combination sensor.	CTRL7 aEN =1, gEN =1, mEN =0 CTRL2 aODR=0xx
Accel + Gyro + Mag (9DOF)	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 aEN =1, gEN =1, mEN =1 CTRL2 aODR=0xx
Wake on Motion (WoM)	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 5.7.5 and see Section 9, Wake on Motion (WoM)	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR = 111

Table 27 Operating Modes (Continued)

Mode	Description	Suggested Configuration
Sensor Modes		
Reset	Software reset asserted	
No Power	VDDIO and VDD low	

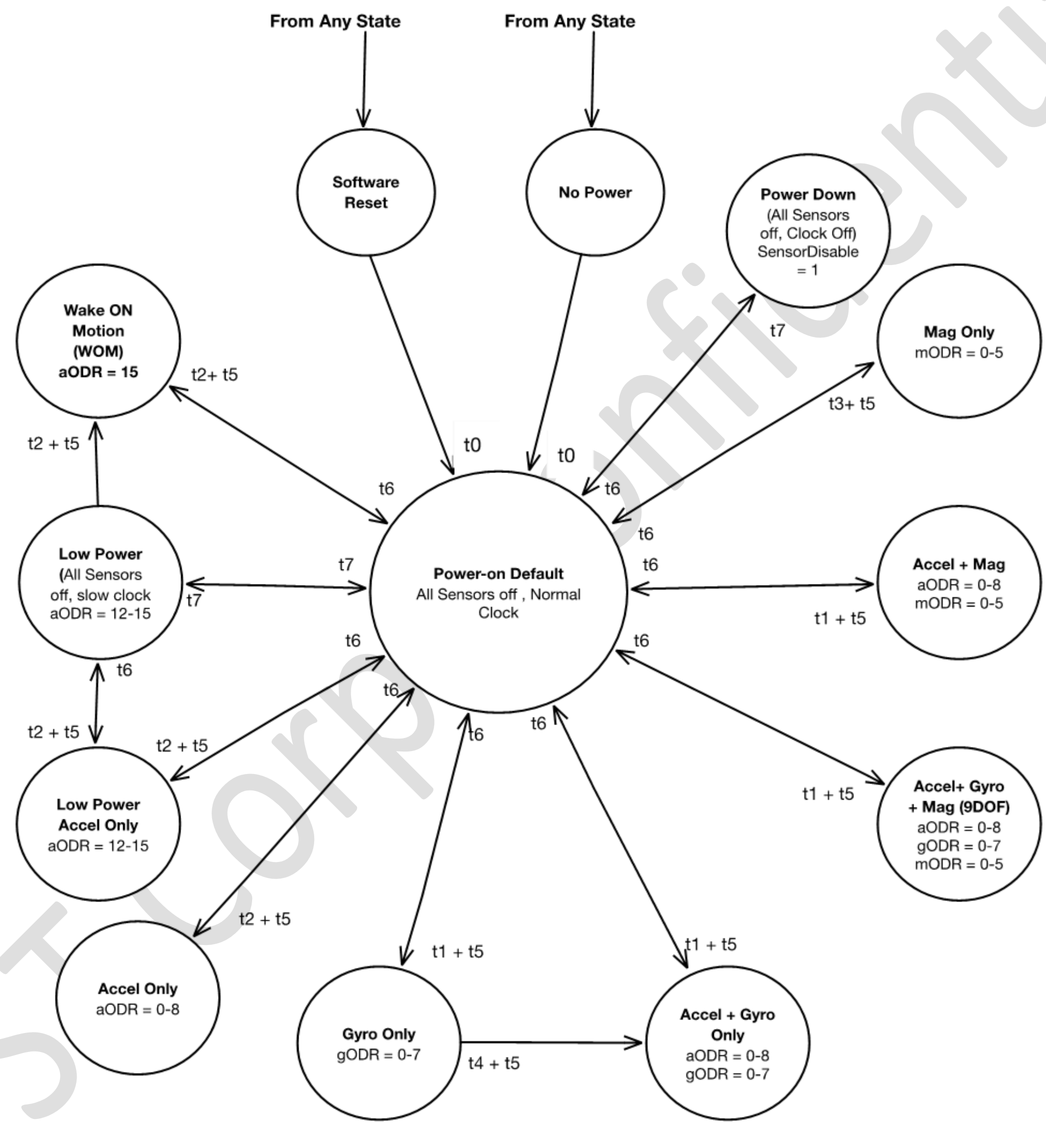


Figure 8. Operating Mode Transition Diagram

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 27 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 t1, t2, t3 and t4, are defined as the time it takes from INT2 going high to data being present. The time, t5 is the time it takes to have a correct representation of the inertial state. t5 is variable and is associated with the user selected Output Data Rate (ODR). We have defined t5 = (3/ODR) to generally represent that time.

t6 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.

t7 is the transition time between various states where the sensors are off.

t0 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 t0 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 t1 (the gyroscope wakeup time) and t5 (the part's filter settling time). t1 is typically 60 ms and t5 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 t2 (the accelerometer wakeup time) and t5 (the part's filter settling time). t2 is typically 3 ms, and t5 is defined as 3/ODR, where ODR is the output data rate in Hertz.
- Time t3 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 t3 + t5, where t5 is defined as 3/ODR, where ODR is the output data rate in Hertz.
- The t7 transition is dependent on data transfer rates and is for I2C at 400 kHz is <100 µs for SPI at 11 Mbps is around 40 µs.

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.

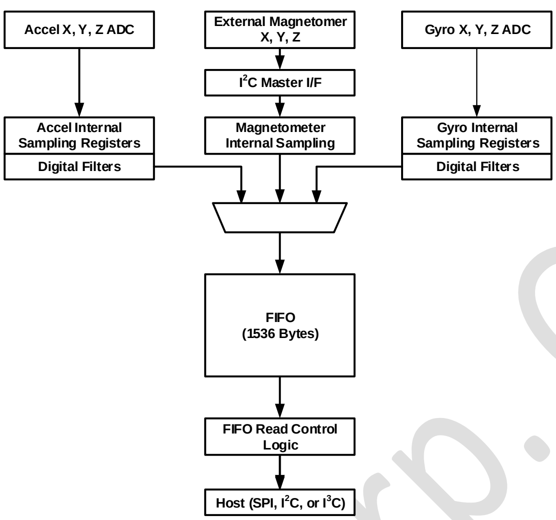


Figure 9. FIFO Data Flow

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/I^{2}C/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.
- Set 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 28. **FIFO Registers Description**

Register Name			
FIFO_CTRL		**Configure FIFO. Register Address: 19 (0x13)**	
Bits	**Name**	**Default**	**Description**
7	FIFO_rd_mode	1’b0	0: Disable FIFO read via FIFO_DATA register. 1: Enable FIFO read via FIFO_DATA register.
6	Reserved	1’b0	Reserved
5:4	wtm<1:0>	2’b0	Set Watermark level. 00 – Do not use. 01 – Set watermark at ¼ of FIFO size. 10 – Set watermark at ½ of FIFO size. 11 – Set watermark at ¾ of FIFO size.
3:2	size<1:0>	2’b0	Set FIFO size. (See Table 29 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
FIFO_DATA		**FIFO Data Register. Register Address: 20 (0x14)**	
Bits	**Name**	**Default**	**Description**
7:0	data<7:0>	8’b0	Read this register to read sensor data out of FIFO.
FIFO_STATUS		**FIFO Status. Register Address: 21 (0x15)**	
Bits	**Name**	**Default**	**Description**
7	resv	1’b0	Reserved
6	wtm	1’b0	Watermark level hit.
5	overflow	1’b0	FIFO over-flow condition.
4	not_empty	1’b0	FIFO not empty.
3:0	fss<3:0>	4’b0	Indicates FIFO storage level. For more information, see Table 29

Table 29. **FIFO Storage Level Indicator fss<3:0> Description**

fss<3:0> Description		**Comments**	
		The FIFO storage level is indicated by the bits fss<3:0> in the FIFO_STATUS register. The value of fss<3:0> represents a coarse value of the FIFO storage level. The coarseness or granularity varies based on the TOTAL FIFO size, as set by the bits size<1:0> in the FIFO_CTRL register. The total FIFO size is the sum of the Accelerometer, Gyroscope and Magnetometer FIFO samples. Each sample for each sensor uses 6 bytes in the FIFO (2 bytes per axis x 3 axes). For example, with 2 sensors active and the bits size<1:0> = [11], the FIFO size is 256 samples (=2x128), which in bytes is 1536 bytes (=6*2*128). In the table below, the Total FIFO Size lists the total number of sensor samples. Note that this value varies based upon the number of sensors enabled and upon the bits size<1:0> in the FIFO CTRL register. The value of the bits fss<3:0> in the FIFO_STATUS register, represents a coarse sample count, whose granularity is given by the number of sensor samples per LSB, as shown below.	
FIFO_CTRL register, bits size<1:0>	**No. of Sensors Enabled (A, G, or M)**	**Total FIFO Size (Total Number of Samples)**	**fss<3:0> Granularity (Number of Sensor Samples per LSB)**
00	1	16	2
01	1	32	4
00	2		
00	3	48	4
10	1	64	8
01	2		
01	3	96	8
11	1	128	16
10	2		
10	3	192	16
11	2	256	32

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 5.7.5 CTRL9 Commands in Detail).

Table 30. **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.

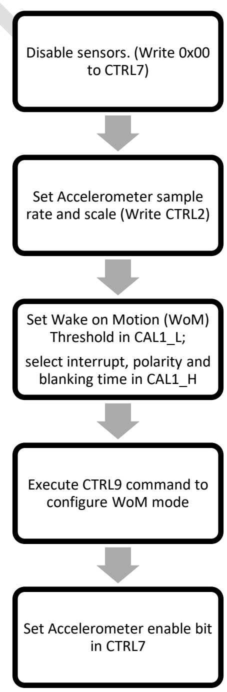


Figure 10. WoM Configuration Commands and Sequence

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 30.

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 30, Registers used for WoM) and execute the WoM configuration CTRL9 command (see write-up for CTRL_CMD_WRITE_WOM_SETTING in Section 5.7.5 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.

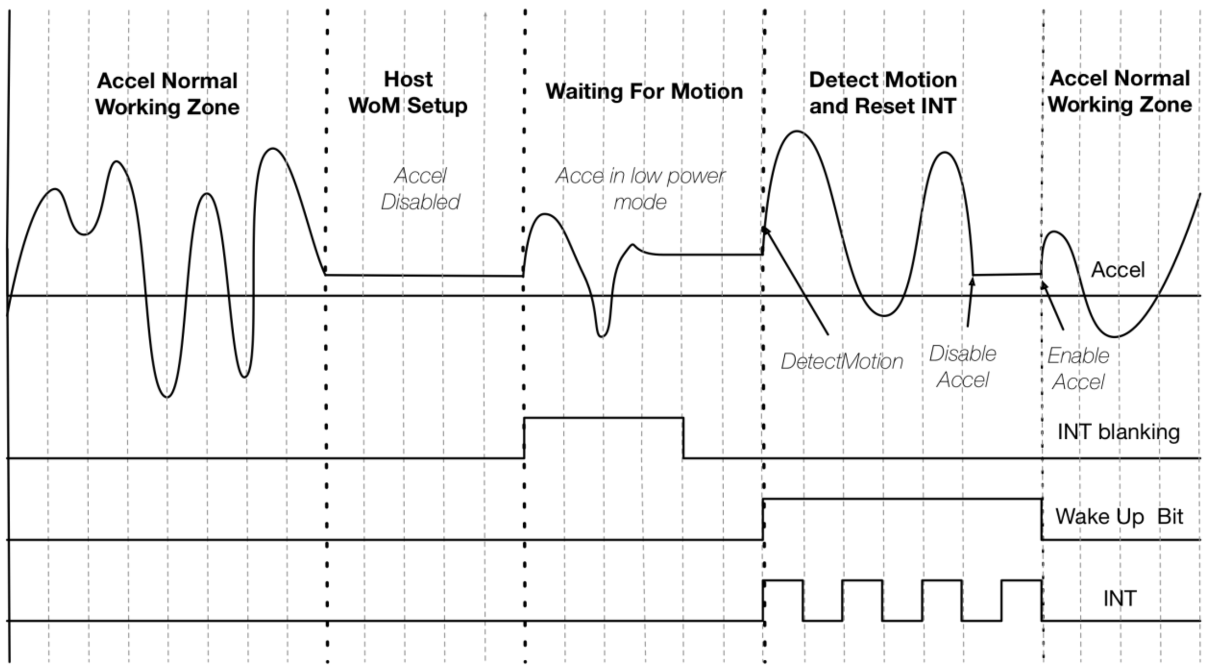


Figure 11. WoM Example Diagram

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. It does this by using an electrostatic force to actuate the inputs of each axis, AX, AY, and AZ. If the accelerometer mechanical structure responds to this input stimulus by sensing 50 mg or greater we can conclude that the accelerometer is functional. The accelerometer Self Test data is available to be read at registers dVX_L, dVX_H, dVY_L, dVY_H, dVZ_L and dVZ_H. The Host can initiate the Self Test at anytime by using the following procedure.

Procedure for accelerometer Self Test:

1. Set CTRL7 register to 0x00.
2. Wait 1 msec.
3. Set CTRL2 register to 0x10 (aFS =2, aODR= 0).
4. Wait 1 msec .
5. Set CTRL2 register to 0x30. This enables aST (accelerometer Self Test enable bit).
6. Wait for the device to drive INT2 high.
7. Read DVX_L, DVX_H, DVY_ L, DVY_H, DVZ_L & DVZ_H registers for the Self Test data.
8. Set CTRL2 register to 0x10 to disable aST.
9. INT2 will be pulled low by the QMI8658C.
10. Set CTRL2 register to 0x00 (back to default value at power up)
11. Based on the data the host processor determines if the accelerometer response is greater or equal to 20 mg.
12. If “yes”, then the accelerometer Self Test has passed.

10.2 Gyroscope Self Test

The gyroscope Self Test is used to determine if the gyroscope is functional and working within acceptable parameters. It does this by applying an electrostatic force to actuate each of the three X, Y, and Z axis of the gyroscope and measures the mechanical response on the corresponding X, Y, and Z axis. If the equivalent magnitude of the output is greater than 300 dps for each axis then we can assume that the gyroscope is functional within acceptable parameters. The gyroscope Self Test data is available to be read at output registers dVX_L, dVX_H, dVY_L, dVY_H, dVZ_L & dVZ_H.

The Host can initiate the self test anytime by using the following procedure.

Procedure for gyroscope Self Test:

1. Set CTRL7 reg. to 0x00;
2. Wait 1 msec
3. Set CTRL3 to 0x38 (gFS = 7, gODR= 0) (full scale = 4096 dps)
4. Wait 1 msec
5. Set CTRL3 register to 0x78. This enables gST (gyroscope Self Test enable bit).
6. Wait for the device to drive INT2 high.
7. Read DVX_L, DVX_H, DVY_ L, DVY_H, DVZ_L & DVZ_H registers for the self test Data.
8. Set CTRL3 register to 0x38 to disable gST.
9. INT2 will be pulled low by device.
10. Set CTRL3 register to 0x00 (back to default value at power up)
11. Based on the data the host processor determines if the gyroscope response is greater or equal to 300 dps.
12. If “yes” then the gyroscope Self Test has passed.

11 Magnetometer Setup

11.1 Magnetometer Description

The QMI8658C provides an I^2C 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^{2}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 21).*

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 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

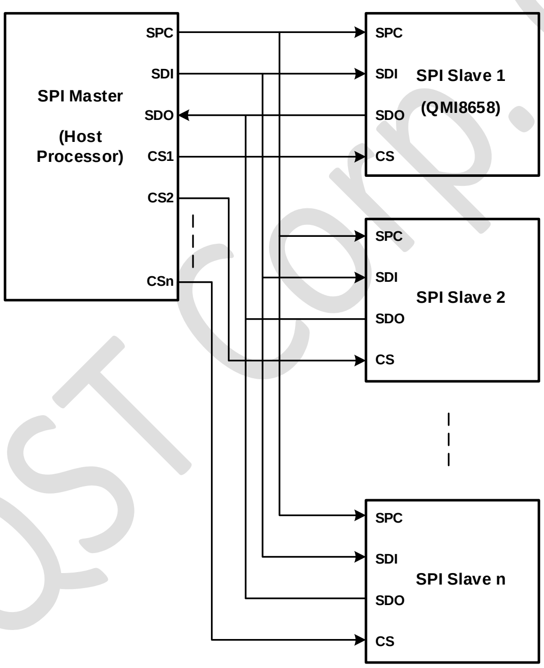


Figure 13. Typical SPI 4-Wire Multi-Slave

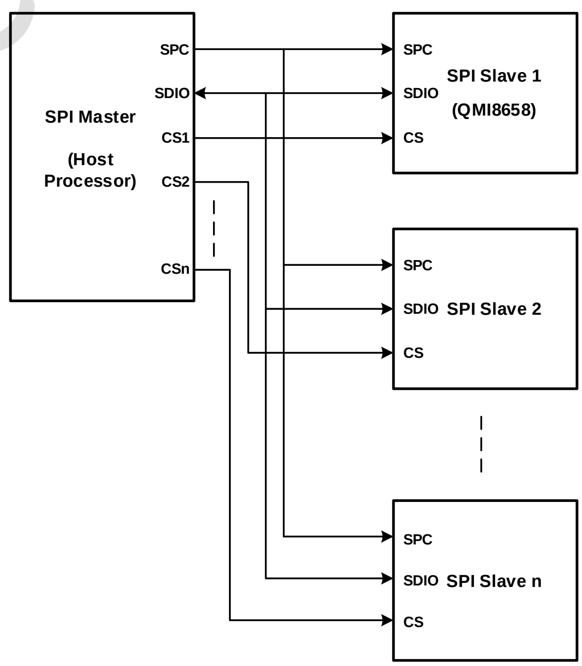


Figure 14. Typical SPI 3-Wire Multi-Slave

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.

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 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 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.

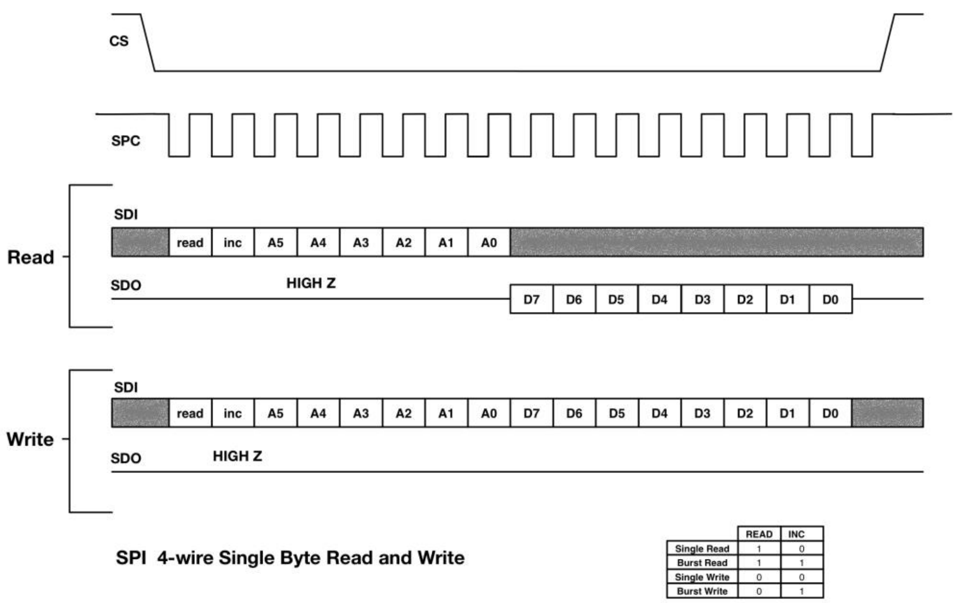


Figure 15. SPI 4-Wire Single Byte Read and Write

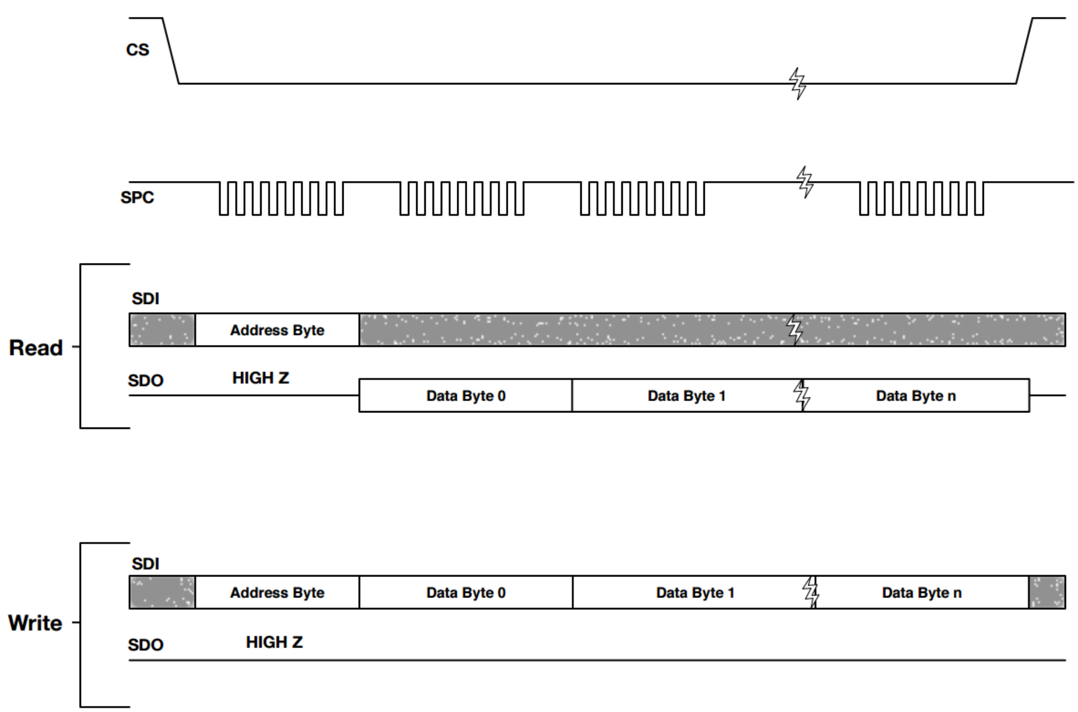
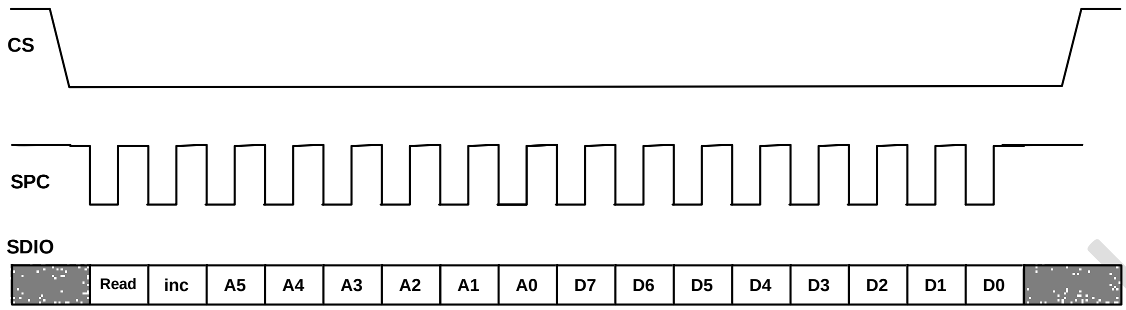


Figure 16. SPI 4-Wire Multi-Byte Read and Write Transactions



SPI 3-wire Single Byte Read and Write

	READ	INC
Single Read	1	0
Burst Read	1	1
Single Write	0	0
Burst Write	0	1

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

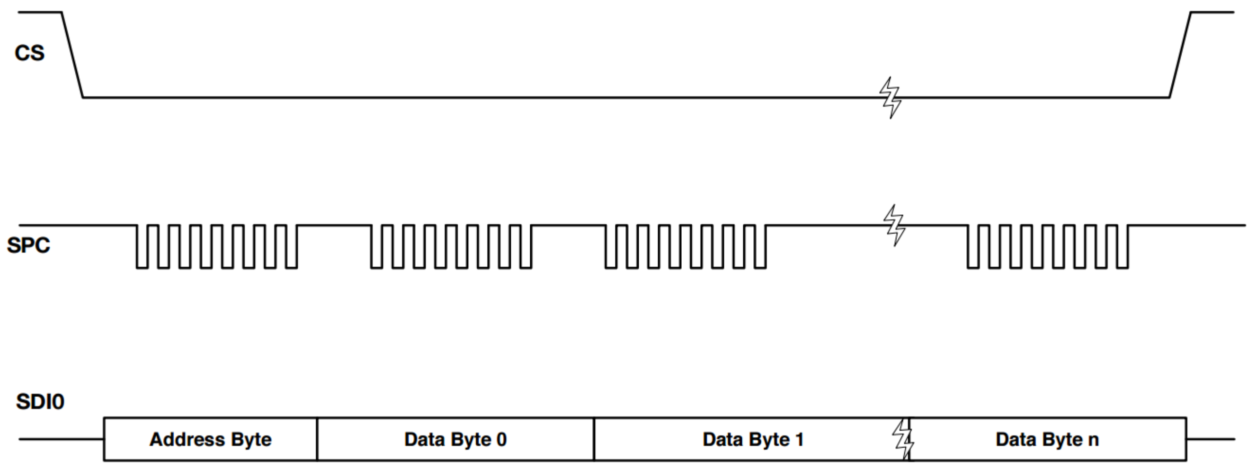


Figure 18. SPI 3-Wire Multi-Byte Read and Write Transactions

12.1.1 SPI Timing Characteristics

The typical operating conditions for the SPI interface are provided in Table 31

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

Table 31. **SPI Interface Timing Characteristics**

Symbol	Parameter	Min.	Max.	Unit
t_{SPC}	SPI Clock Cycle	66.6		ns
f_{SPC}	SPI Clock Frequency		15	MHz
ts_{CS}	CS Setup Time	6		ns
th_{CS}	CS Hold Time	8		ns
ts_{SDI}	SDI Input Setup Time	5		ns
th_{SDI}	SDI Input Hold Time	15		ns
tv_{SDO}	SDO Time for Valid Output		50	ns
th_{SDO}	SDO Hold Time for Output	9		ns
td_{SDO}	SDO Disable Time for Output		50	ns
ts_{SDIO}	SDIO Address Setup Time	5		ns
th_{SDIO}	SDIO Address Hold Time	15		ns
tv_{SDIO}	SDIO Time for Valid Data		50	ns
tcz_{SDIO}	SDIO Time from SPC to High Z		50	ns
tz_{SDIO}	SDIO Time from CS to High Z		50	ns

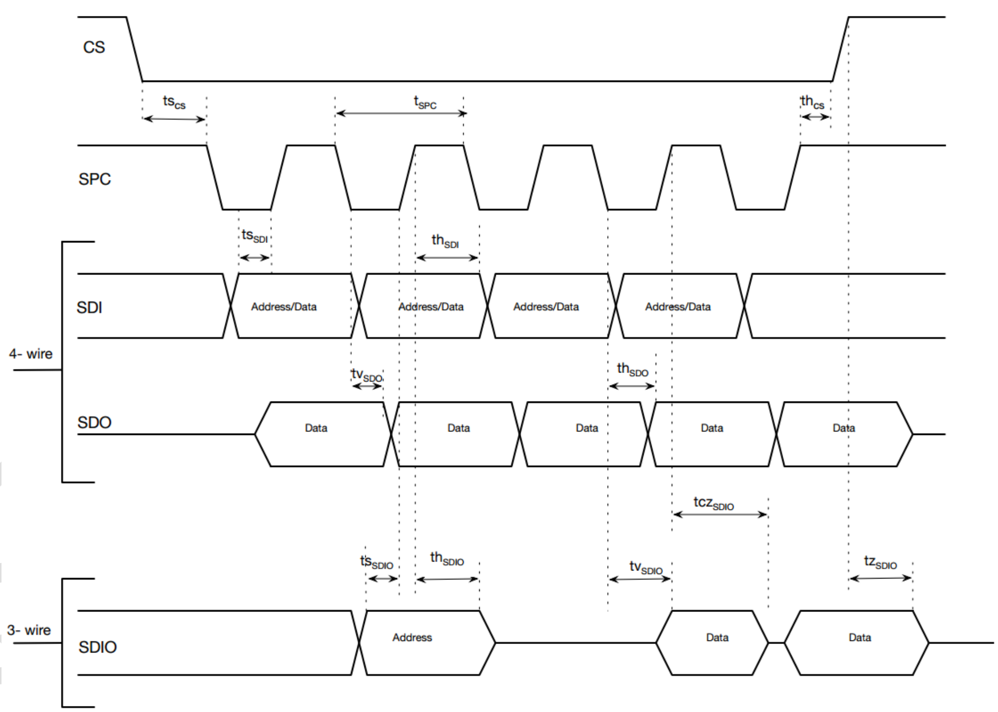


Figure 19. Timing Characteristics for SPI 3- and 4-Wire Interfaces

12.2 I²C Interface

Table 32 provides the I²C interface timing characteristics while Figure 20 and Figure 21 illustrate the I²C timing for both fast and standard modes, respectively.

During the slave device selection phase, the I²C master supplies the 7-bit I²C 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 I²C standard, such as pull-up resistor sizing the user is referred to "UM10204 I²C-bus specification and user manual," published by NXP B.V.

Table 32. **I²C Timing Characteristics**

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

Note:

14. C_B is the bus capacitance.

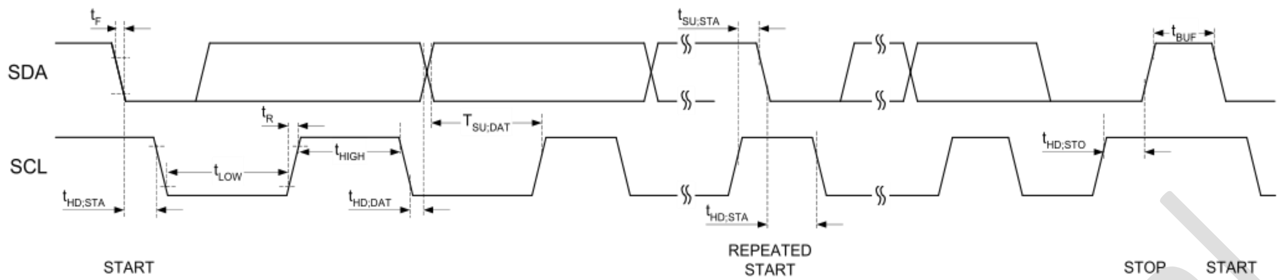


Figure 20. I²C Standard Mode Interface Timing

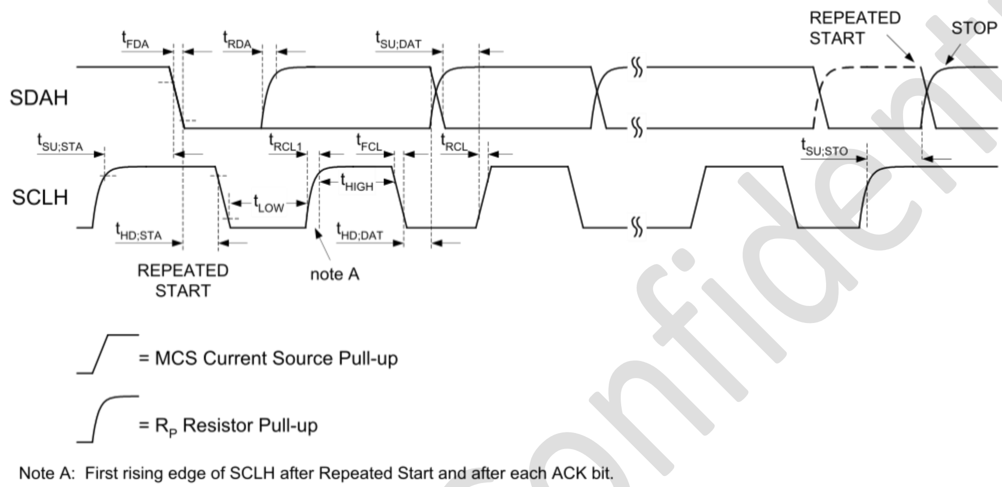


Figure 21. I²C Fast Mode Interface Timing

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

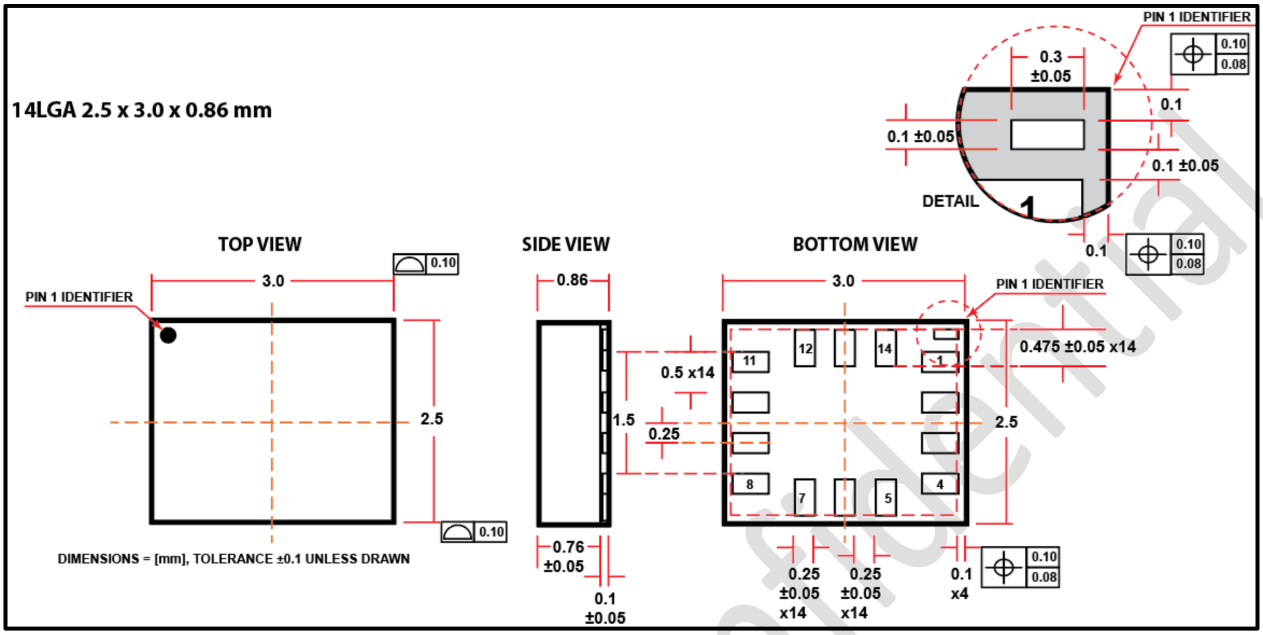
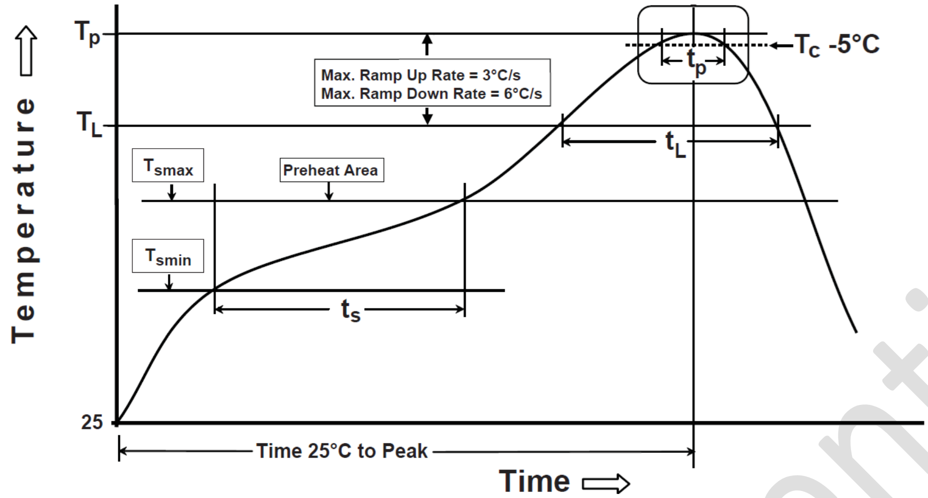


Figure 22. 14 Pin LGA 2.5 x 3.0 x 0.86 mm Package

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 ≤30°C and Relative Humidity: 60%RH.

14 Document Information

14.1 Revision History

Revision	Revision Date	Description
0.4	April 21, 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.
0.51	August 24, 2020	Updated Table 12 and SPI description.

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