QMI8658C DATASHEET

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QMI8658C
Low Noise, Wide Bandwidth 6D Inertial Measurement Unit with Motion Co-Processor and Sensor Fusion

Features

- Low 15 mdps/√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 200µg/√Hz accelerometer
- Host (slave) interface supports MIPI™ I3C, I^2C, and 3-wire or 4-wire SPI
- 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
- 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 ±16°/s to ±2048°/s for gyroscope and ±2 g to ±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 ±3° pitch and roll orientation, and a ±5° yaw/heading typical specification.

With tight board-level gyroscope sensitivity of ±3%, gyroscope noise density of 15 mdps/√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^2C and 3-wire or 4-wire SPI) .

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

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 C	DDDD D – 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

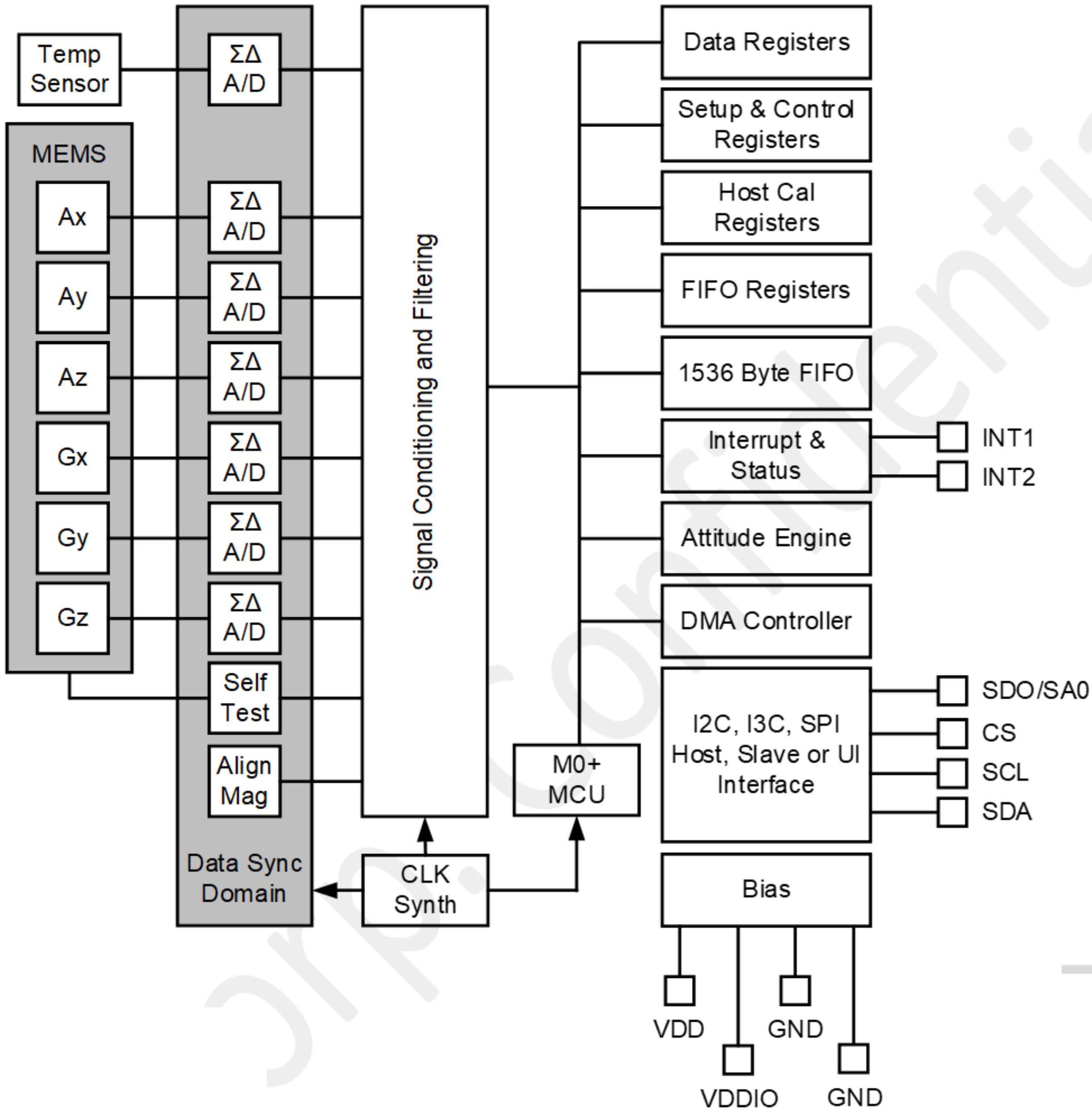


Figure 2. Internal Block Diagram

1.4 Interface Operating Modes

The QMI8658C can operate in below mode, as shown in the Figure below.

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: I²C, 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.

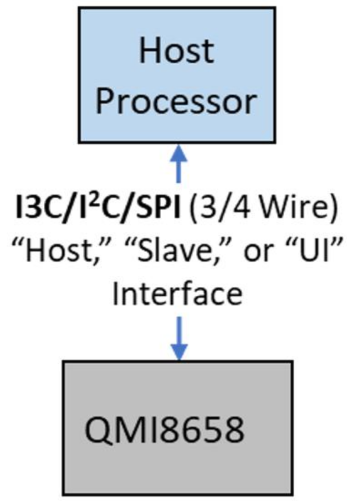


Figure 3. Operating modes

1.5 Application Diagrams

The typical application diagrams are shown in this section.

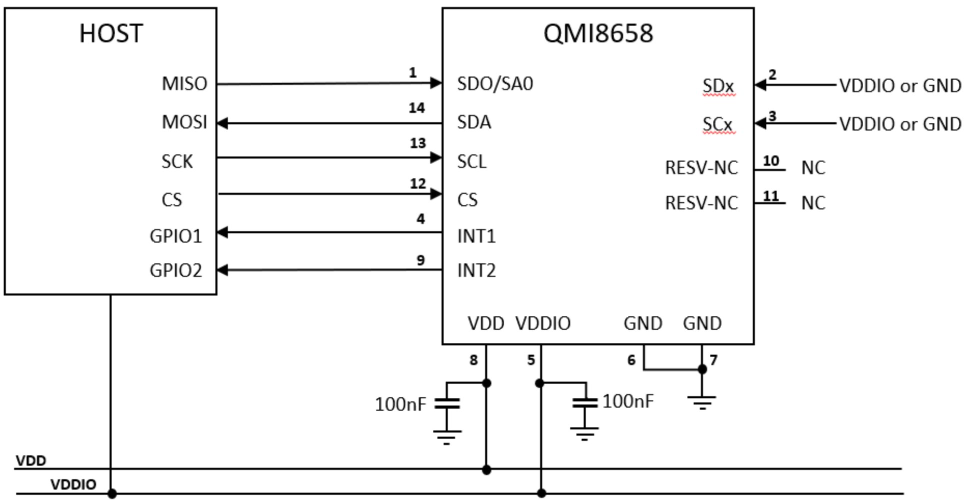


Figure 4. 4-Wire SPI-UI mode

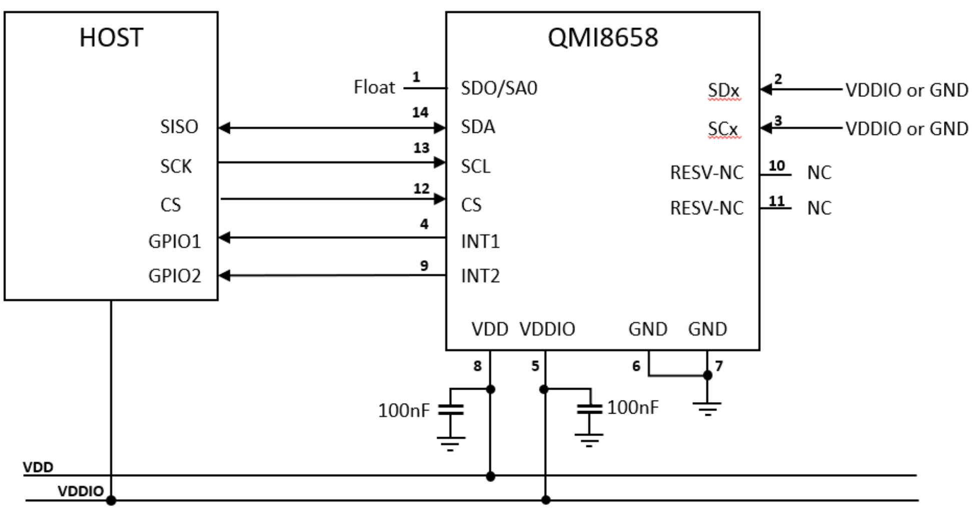


Figure 5. 3-Wire SPI-UI mode

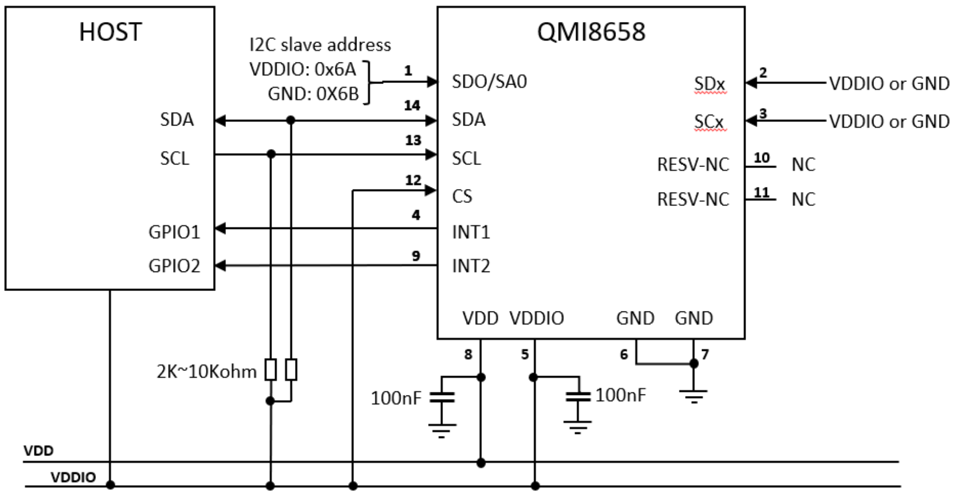


Figure 6. I3C/I^{2}C-UI mode

Note: As there is internal 200Kohm pull-up resistor, pull SDO/SA0 low will cost more current then pull it high.

1.6 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.

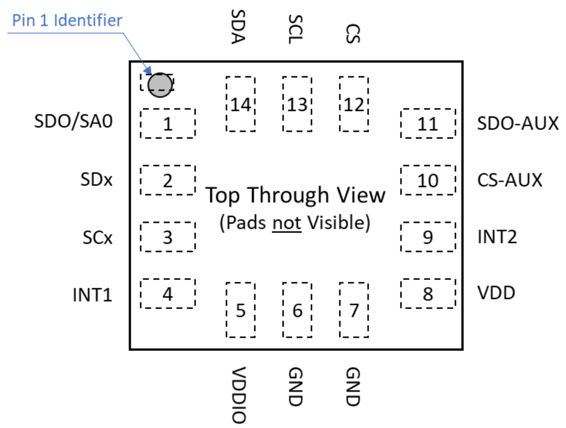


Figure 7. Pins Face Down (Top View)

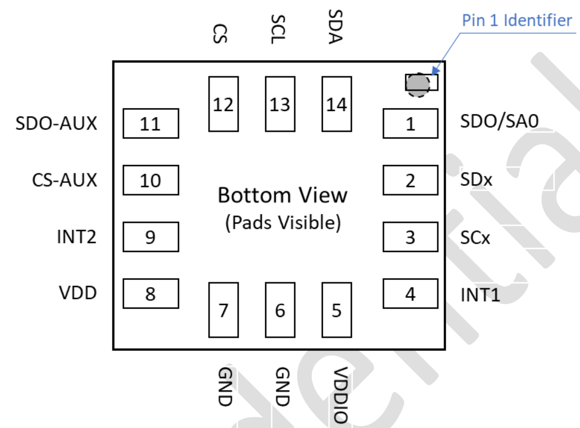


Figure 8. Pins Face Up (Bottom View)

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

Notes:

1. This pin has an internal 200KΩ pull up resistor.
2. The internal pull-up resistor can be disabled by CTRL9 command (CTRL_CMD_SET_RPU). Refer to 5.9.5 for details.
3. Refer to Section 12 for detailed configuration information.

1.7 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	2KΩ ~ 10 kΩ

Note:

4. R_{pu} resistors are only needed when the Host Serial Interface is configured for I^2C (see I2C 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-down 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.

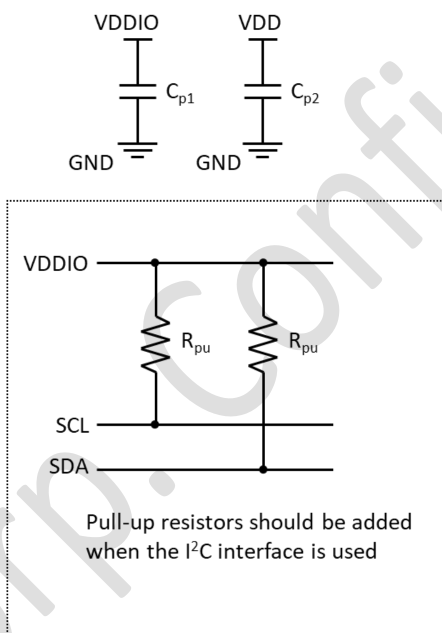


Figure 9. Typical Electrical Connections

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 ±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.

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 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 ΣΔ-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/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

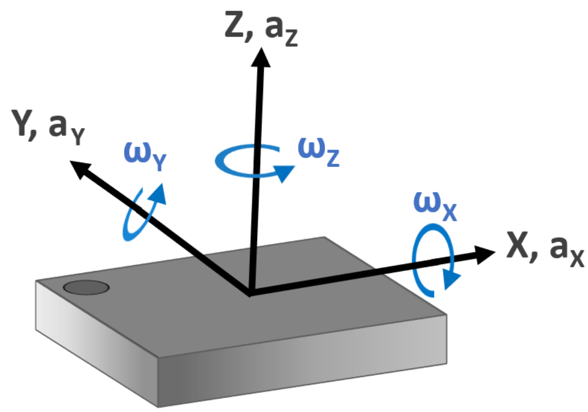


Figure 10. Chip Orientation Coordinate System

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 coordinate 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.

Figure 10 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
Tr(7)	VDDIO rising time (from 0.1V to 1.7V)			100	us
V_{IL}	Digital Low Level Input Voltage			0.3 *VDDIO	V
V_{IH}	Digital High Level Input Voltage	0.7 *VDDIO		VDDIO + 0.3	V
V_{OL}	Digital Low Level Output Voltage			0.1 *VDDIO	V
V_{OH}	Digital High Level Output Voltage	0.9 *VDDIO			V

Notes:
7. There is no rising time limitation for VDD.

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)	150		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)	±1		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[8]	150		ms	From Software Reset, No Power, or Power Down to Power-on Default state = t0 in Figure 11
	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 11.

Note:

8. 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	23.5		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[9]	150		ms	From Software Reset, No Power, or Power Down to Power-on Default state = t0 in Figure 11
	Gyro Turn On Time	60 ms + 3/ODR		ms	from Power-On Default = t1 11
	Temperature Coefficient of Offset (TCO)	±0.1		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:
9. 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.

There are two sources of ODR frequency of accelerometer based on the operation mode. If only accelerometer is enabled, the ODR frequency is derived from the internal oscillator. If both accelerometer and gyroscope (6DOF mode) are enabled, the ODR frequency is derived from the natural frequency of gyroscope, which will nominally be 0.94 multiply the ODR values of enabling accelerometer only. Table 10 shows the two sets of ODR frequency, which can be referenced for later descriptions in the datasheet. Refer to section 5.4 for detailed ODR configuration.

Table 10. Accelerometer Noise Density

Mode	High-Resolution									Low-Power				Unit
ODR (Accel only)				1000	500	250	125	62.5	31.25	128	21	11	3	Hz
ODR (Accel + Gyro)	7520	3760	1880	940	470	235	117.5	58.75	29.375					Hz
Typical Noise Density	200	200	200	200	200	200	200	200	200	125	180	285	700	µg/√Hz

Table 11. Accelerometer Filter Characteristics (Accelerometer only)(10)

Mode	High-Resolution									Low-Power				Unit
ODR	8000	4000	2000	1000	500	250	125	62.5	31.25	128	21	11	3	Hz
Bandwidth (Default, 27.5% of ODR)	NA	NA	NA	275	137.5	68.8	34.4	17.2	8.6	35.2	5.8	3.0	0.8	
Bandwidth with Low-Pass Filter Enabled Mode 00 (2.66% of ODR)	NA	NA	NA	26.6	13.3	6.7	3.3	1.7	0.8	3.4	0.6	0.3	0.1	
Bandwidth with Low-Pass Filter Enabled Mode 01 (3.63% of ODR)	NA	NA	NA	36.3	18.2	9.1	4.5	2.3	1.1	4.6	0.8	0.4	0.1	
Bandwidth with Low-Pass Filter Enabled Mode 10 (5.39% of ODR)	NA	NA	NA	53.9	27	13.5	6.7	3.4	1.7	6.9	1.1	0.6	0.2	
Bandwidth with Low-Pass Filter Enabled Mode 11 (13.37% of ODR)	NA	NA	NA	133.7	66.9	33.4	16.7	8.4	4.2	17.1	2.8	1.5	0.4	

Note:

10. When only accelerometer is enabled, the ODR is derived from the internal oscillator.

Table 12. Accelerometer Filter Characteristics (6DOF)(11)

Mode	High-Resolution									Low-Power				Unit
ODR	7520	3760	1880	940	470	235	117.5	58.75	29.375	128	21	11	3	Hz
Bandwidth (Default, 27.5% of ODR)	2068	1034	517	258.5	129.3	64.6	32.3	16.2	8.1	NA	NA	NA	NA	
Bandwidth with Low-Pass Filter Enabled Mode 00 (2.66% of ODR)	200	100	50	25	12.5	6.3	3.1	1.6	0.8	NA	NA	NA	NA	
Bandwidth with Low-Pass Filter Enabled Mode 01 (3.63% of ODR)	273	136.5	68.2	34.1	17.1	8.5	4.3	2.1	1.1	NA	NA	NA	NA	
Bandwidth with Low-Pass Filter Enabled Mode 10 (5.39% of ODR)	405.3	202.7	101.3	50.7	25.3	12.7	6.3	3.2	1.6	NA	NA	NA	NA	
Bandwidth with Low-Pass Filter Enabled Mode 11 (13.37% of ODR)	1005.4	502.7	251.4	125.7	62.8	31.4	15.7	7.9	3.9	NA	NA	NA	NA	

Note:

11. When both accelerometer and gyroscope are enabled, all frequencies are ±5% and are synchronized to the nature frequency of gyroscope.

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 nature frequency.

Table 13. Gyroscope Filter Characteristics

Mode	High-Resolution									Unit
ODR	7520	3760	1880	940	470	235	117.5	58.75	29.375	Hz
Bandwidth (Default, 27.5% of ODR)	2068	1034	517	258.5	129.3	64.6	32.3	16.2	8.1	
Bandwidth with Low-Pass Filter Enabled Mode 00 (2.66% of ODR)	200	100	50	25	12.5	6.3	3.1	1.6	0.8	
Bandwidth with Low-Pass Filter Enabled Mode 01 (3.63% of ODR)	273	136.5	68.2	34.1	17.1	8.5	4.3	2.1	1.1	
Bandwidth with Low-Pass Filter Enabled Mode 10 (5.39% of ODR)	405.3	202.7	101.3	50.7	25.3	12.7	6.3	3.2	1.6	
Bandwidth with Low-Pass Filter Enabled Mode 11 (13.37% of ODR)	1005.4	502.7	251.4	125.7	62.8	31.4	15.7	7.9	3.9	

3.7 Electrical Characteristics

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

Table 14 describes the names for the pins in different functions. The later descriptions will directly use the function name in different scenarios instead of the pin name.

Table 14. Pin Name Mapped to Function Name

Pin Number	Type	Pin Name	Function Name in 4-wire SPI	Function Name in 3-wire SPI	Function Name in Host I2C	Function Name in I2C Master
1	O	SDO/SA0	SDO		SA0	
2	IO	SDx				SDA
3	IO	SCx				SCL
12	I	CS	CS	CS		
13	IO	SCL	SPC	SPC	SCL	
14	IO	SDA	SDI	SDIO	SDA	

Table 15. 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 and Fast Mode are supported)				400	kHz
f_{SCL3}	Host I3C Interface Speed	Standard Data Rate (SDR)			12.5	MHz

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 16. 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 17. Current Consumption for Gyroscope Only Typical Sensor Mode (Accelerometer Disabled)

Mode		High-Resolution									Unit
ODR		7520	3760	1880	940	470	235	117.5	58.75	29.375	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 18. Current Consumption for 6DOF Typical Sensor Mode (Accelerometer and Gyroscope Enabled). VDD = VDDIO = 1.8V

Mode		High-Resolution									Unit
ODR		7520	3760	1880	940	470	235	117.5	58.75	29.375	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 19. 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 20. 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	tbd	tbd	tbd	tbd	tbd	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 0.* The HOST should synchronize to the interrupt, INT2, signal to get valid temperature readings.

Table 21. 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^2C.

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 22 for UI Interface: contain all data for 9D sensors to be accessed from the UI interface – either I^2C or SPI.

Table 22. 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	Reserved
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	Motion Detection Control
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_WTM_TH	rw	19	13	00010011	00000000	FIFO watermark level, in ODRs
FIFO_CTRL	rw	20	14	00010100	00000000	FIFO Setup
FIFO_SMPL_CNT	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
Status Registers						
STATUSINT	r	45	2D	00101101	00000000	Sensor Data Availability with the Locking mechanism, CmdDone (CTRL9 protocol bit).
STATUS0	r	46	2E	00101110	00000000	Output Data Over Run and Data Availability.
STATUS1	r	47	2F	00101111	00000000	Miscellaneous Status: Wake on Motion.
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	32	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	
dQW_L	r	73	49	01001001	00000000	Quaternion Increment dQW dQW_L – lower 8 bits. dQW_H – upper 8 bits
dQW_H	r	74	4A	01001010	00000000	
dQX_L	r	75	4B	01001011	00000000	Quaternion Increment dQX dQX_L – lower 8 bits. dQX_H – upper 8 bits
dQX_H	r	76	4C	01001100	00000000	
dQY_L	r	77	4D	01001101	00000000	Quaternion Increment dQY dQY_L – lower 8 bits. dQY_H – upper 8 bits
dQY_H	r	78	4E	01001110	00000000	
dQZ_L	r	79	4F	01001111	00000000	Quaternion Increment dQZ dQZ_L – lower 8 bits. dQZ_H – upper 8 bits
dQZ_H	r	80	50	01010000	00000000	
dVX_L	r	81	51	01010001	00000000	Velocity Increment along X-axis dVX_L – lower 8 bits. dVX_H – upper 8 bits
dVX_H	r	82	52	01010010	00000000	
dVY_L	r	83	53	01010011	00000000	Velocity Increment along Y-axis dVY_L – lower 8 bits. dVY_H – upper 8 bits
dVY_H	r	84	54	01010100	00000000	
dVZ_L	r	85	55	01010101	00000000	Velocity Increment along Z-axis dVZ_L – lower 8 bits. dVZ_H – upper 8 bits
dVZ_H	r	86	56	01010110	00000000	
AE_REG1	r	87	57	01010111	00000000	AttitudeEngine Register 1
AE_REG2	r	88	58	01011000	00000000	AttitudeEngine Register 2
Reset Register						

RESET	w	96	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 and gyroscope can be independently configured. Table 23 summarizes these pertinent registers.

Table 23. 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, and Gyroscope Using sEN, aEN, and gEN bits, 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
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 – 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
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 24 summarizes the operation of the AttitudeEngine mode.

Table 24. 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^{-1}	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_OVFLOW		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 25. 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 26. Configuration Registers Description

Register Name			
CTRL1		**Serial Interface and Sensor Enable. Register Address: 2 (0x02)**	
Bits	**Name**	**Default**	**Description**
7	SIM	1’b0	0: Enables 4-wire SPI interface 1: Enables 3-wire SPI interface
6	ADDR_AI	1’b0	0: Serial interface (SPI or I^2C) address do not auto increment. 1: Serial interface (SPI or I^2C) address auto increment
5	BE	1’b1	0: Serial interface (SPI or I^2C) read data little endian 1: Serial interface (SPI or I^2C) 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
CTRL2		**Accelerometer Settings: Address: 3 (0x03)**	
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>[12][13]	4’b0	Set Accelerometer Output Data Rate (ODR): (see table below)

Setting	ODR Rate (Hz) (Accel only)	ODR Rate (Hz) (6DOF)[13]	Mode	Duty Cycle
0000	N/A	7520	Normal	100%
0001	N/A	3760	Normal	100%
0010	N/A	1880	Normal	100%
0011	1000	940	Normal	100%
0100	500	470	Normal	100%
0101	250	235	Normal	100%
0110	125	117.5	Normal	100%
0111	62.5	58.75	Normal	100%
1000	31.25	29.375	Normal	100%
1001	N/A	N/A		
1010	N/A	N/A		
1011	N/A	N/A		
1100	128	N/A	Low Power	100%
1101	21	N/A	Low Power	58%
1110	11	N/A	Low Power	31%
1111	3	N/A	Low Power	8.5%

Table 26 Configuration Register Description (Continued)

Register Name	
CTRL3	**Gyroscope Settings: Address 4 (0x04)**

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> (13)	4'b0	Set Gyroscope Output Data Rate (ODR): (see table below)

Setting	ODR Rate (Hz)	Mode	Duty Cycle
0000	7520	Normal	100%
0001	3760	Normal	100%
0010	1880	Normal	100%
0011	940	Normal	100%
0100	470	Normal	100%
0101	235	Normal	100%
0110	117.5	Normal	100%
0111	58.75	Normal	100%
1000	29.375	Normal	100%
1001	N/A		
1010	N/A		
1011	N/A		
1100	N/A		
1101	N/A		
1110	N/A		
1111	N/A		

CTRL4		**Reserved – Special Settings. Register Address: 5 (0x05)**	
Bits	**Name**	**Default**	**Description**
7:0	Reserved	0x00	Not Used

Note:

12. The accelerometer low power mode is only available when the gyroscope is disabled
13. In 6DOF mode (accelerometer and gyroscope are both enabled), the ODR is derived from the nature frequency of gyroscope, refer to section 3.5 for more information.

Table 26 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 — 2.66% of ODR 01 — 3.63% of ODR 10 — 5.39% of ODR 11 — 13.37% 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 — 2.66% of ODR 01 — 3.63% of ODR 10 — 5.39% of ODR 11 — 13.37% 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.
CTRL6		**Attitude Engine ODR and Motion on Demand: Address: 7 (0x07)**	
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) Setting / ODR Rate (Hz): 000 — 1 001 — 2 010 — 4 011 — 8 100 — 16 101 — 32 110 — 64

Table 26 Configuration Register Description (Continued)

Register Name			
CTRL7		**Enable Sensors and Configure Data Reads. Register Address: 8 (0x08)**	
Bits	**Name**	**Default**	**Description**
7	syncSmpl	1'b0	0: Disable syncSmple mode 1: Enable syncSmple 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	Reserved	1'b0	
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		**Motion Detection Control. Register Address: 9 (0x09)**	
Bits	**Name**	**Default**	**Description**
7	CTRL9 Handshaking Type	1b'0	0: use INT1 as CTRL9 handshake 1: use STATUSINT.bit7 as CTRL9 handshake
6	INT pin for Motion detection event	1b'0	0: INT2 is used for motion detection event interrupt 1: INT2 is used for motion detection event interrupt Note: this bit will influence the any/no/sig-motion, pedometer, tap detection interrupt
5	reserved	1b'0	
4	Pedometer Enable	1b'0	0: disable Pedometer engine 1: enable Pedometer engine
3	Significant Motion Enable	1b'0	0: disable Significant Motion engine 1: enable Significant Motion engine
2	No Motion Enable	1b'0	0: disable No Motion engine 1: enable No Motion engine
1	Any Motion Enable	1b'0	0: disable Any Motion engine 1: enable Any Motion engine
0	Tap Enable	1b'0	0: disable Tap engine 1: enable Tap engine
Register Name			
CTRL9		Host Commands. Register Address: 10 (0x0A), Referred to: **5.9 CTRL 9 Functionality (Executing Pre-defined Commands)**	

5.5 FIFO Registers

Table 27. FIFO Control/Status/Data Registers

Register Name			
FIFO_WTM_TH	**FIFO Watermark Register Address: 19 (0x13)**		
Bits	**Name**	**Default**	**Description**
7:0	FIFO_WTM	8'h0	Number of ODRs needed to trigger watermark
FIFO_CTRL	**FIFO Control Register Address: 20 (0x14)**		
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
FIFO_SMPL_CNT	**FIFO Sample Count Register Address: 21 (0x15)**		
Bits	**Name**	**Default**	**Description**
7:0	FIFO_SMPL_CNT_LSB	8'b0	8 LS bits of FIFO Sample Count (in bytes).
FIFO_STATUS	**FIFO Status. Register Address 22 (0x16)**		
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_OVFLOW	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.

5.6 Status and Time Stamp Registers

Table 28. Status and Time Stamp Registers

Register Name			
STATUSINT		**Sensor Data Available and Lock Register Address: 45 (0x2D)**	
Bits	**Name**	**Default**	**Description**
7	Ctrl9 CmdDone	1'b0	Bit read by Host Processor as part of CTRL9 register protocol. Used to indicate ctrl9 Command was done. Please Refer to 5.9.3 and 5.9.4 for more details. 0: Not Completed 1: Done
6:2	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.
STATUS0		**Output Data Status Register Address: 46 (0x2E)**	
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	Reserved	1'b0	
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	Significant Motion	1'b0	0: No Significant-Motion was detected 1: Significant-Motion was detected

6	No Motion	1'b0	0: No No-Motion was detected 1: No-Motion was detected
5	Any Motion	1'b0	0: No Any-Motion was detected 1: Any-Motion was detected
4	Pedometer	1'b0	0: No step was detected 1: step was detected
3	Reserved	1'b0	
2	Reserved	1'b0	
1	TAP	1'b0	0: No Tap was detected 1: Tap was detected
0	Reserved	1'b0	

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	

5.7 Sensor Data Output Registers

Table 29. Sensor Data Output Registers 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	

Continued on the following page

Table 29 Sensor Data Output Registers Description (Continued)

Register Name			
dQ[1,2,3,4]_[H,L]		**Quaternion Output. Register Addresses: 73 – 80 (0x49 – 0x50)**	
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	
dV[X,Y,Z]_[H,L]		**Delta Velocity Output. Register Address: 81 – 86 (0x51– 0x56)**	
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	
AE_REG1		**AttitudeEngine Register 1, Address: 87 (0x57)**	
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 29 Sensor Data Output Registers Description (Continued)

Register Name			
AE_REG2	**AttitudeEngine Register 2, Address: 88 (0x58)**		
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 30. AttitudeEngine Modes and Output Table

<table>
<tr><th colspan="2">Mode/Outputs</th><th>dQ</th><th>dV</th><th>M</th><th>TIMESTAMP</th><th>Comments on TIMESTAMP</th></tr>
<tr><td colspan="7">AttitudeEngine in ODR Mode (Accelerometer and Gyroscope Enabled)</td></tr>
<tr><td>CTRL6 Register</td><td>sMoD=0</td><td rowspan="6">Quaternion Increment</td><td rowspan="6">Velocity Increment</td><td rowspan="6">No Data</td><td rowspan="6">AttitudeEngine Sample Count</td><td rowspan="6">24-bit data. Count starts at 1, 16,777,216 count wraps to 0, i.e. Mod(16,777,216)</td></tr>
<tr><td rowspan="5">CTRL7 Register</td><td>gSN=0</td></tr>
<tr><td>sEN=1</td></tr>
<tr><td>aEN=1</td></tr>
<tr><td>gEN=1</td></tr>
<tr><td>mEN=0</td></tr>
<tr><td colspan="7">AttitudeEngine in Motion on Demand (MoD) mode (Accelerometer and Gyroscope enabled)</td></tr>
<tr><td>CTRL6 Register</td><td>sMoD=1</td><td rowspan="6">Quaternion Increment</td><td rowspan="6">Velocity Increment</td><td rowspan="6">No Data</td><td rowspan="6">Gyroscope Samples in Integration Window</td><td rowspan="6">24-bit data. Count starts at 1, 16,777,216 count wraps to 0, i.e. Mod(16,777,216)</td></tr>
<tr><td rowspan="5">CTRL7 Register</td><td>gSN=0</td></tr>
<tr><td>sEN=1</td></tr>
<tr><td>aEN=1</td></tr>
<tr><td>gEN=1</td></tr>
<tr><td>mEN=0</td></tr>
<tr><td colspan="7">AttitudeEngine with Raw Magnetometer in ODR Mode (Accelerometer, Gyroscope and Magnetometer Enabled)</td></tr>
<tr><td>CTRL6 Register</td><td>sMoD=0</td><td rowspan="6">Quaternion Increment</td><td rowspan="6">Velocity Increment</td><td rowspan="6">Initial Raw Mag Data</td><td rowspan="6">AttitudeEngine Sample Count</td><td rowspan="6">24-bit data. Count starts at 1, 16,777,216 count wraps to 0, i.e. Mod(16,777,216)</td></tr>
<tr><td rowspan="5">CTRL7 Register</td><td>gSN=0</td></tr>
<tr><td>sEN=1</td></tr>
<tr><td>aEN=1</td></tr>
<tr><td>gEN=1</td></tr>
<tr><td>mEN=1</td></tr>
</table>

5.8 Reset register

Table 31. Reset Register Description

Register Name			
RESET		**Register Address: 96 (0x60)**	
Bits	**Name**	**Default**	**Description**
7:0	RESET	0x00	Soft Reset Register - Write 0xB0 to this register from any modes, will trigger the sensor reset process immediately.

5.9 CTRL 9 Functionality (Executing Pre-defined Commands)

5.9.1 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 setting STATUSINT.bit7 to 1， and raising INT1 interrupt if CTRL8.bit7 == 0. The host must acknowledge this by reading STATUSINT.bit7, This is the CmdDone bit. After this read, the QMI8658C clear the STATUSINT.bit7 to 0 and pulls down the INT1 interrupt if CTRL8.bit7 == 0. 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**).

5.9.2 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 set STATUSINT.bit7 to 1, and raise INT1(if CTRL8.bit7 == 0), once it has executed the appropriate function based on the command value.
4. The host must acknowledge this by reading STATUSINT.bit7 (CmdDone) which is reset to 0 on reading the register, completing the CTRL9 transaction. And INT1 is pulled low upon the register read if CTRL8.bit7 == 0.
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 32. 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

5.9.3 Ctrl9R (CTRL9 Protocol - Read)

1. Write Ctrl9 register 0x0A with the appropriate Command value.
2. The Device will set STATUSINT.bit7 to 1, and raise INT1 (if CTRL8.bit7 == 0), once it has executed the appropriate function based on the command value.
3. The host must acknowledge this by reading STATUSINT.bit7 (CmdDone) which is then reset to 0 upon reading the register, completing the CTRL9 transaction. INT1 is pulled low upon the register read if CTRL8.bit7 == 0.
   Data is available from the device at this time. The location of the data is specified separately for each of the Commands.

5.9.4 Ctrl9 (CTRL9 Protocol Acknowledge)

1. Write CTRL9 register 0x0A with the appropriate Command value.
2. The Device set STATUSINT.bit7 to 1, and raise INT1 (if CTRL8.bit7 == 0), once it has executed the appropriate function based on the command value.
3. The host must acknowledge this by reading STATUSINT.bit7 (CmdDone) which is then reset to 0 upon reading the register, completing the CTRL9 transaction. INT1 is pulled low upon the register read if CTRL8.bit7 == 0.

Table 33. 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_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
CTRL_CMD_AHB_CLOCK_GATING	0x12	WCtrl9	Internal AHB clock gating switch
CTRL_CMD_ON_DEMAND_CALIBRATION	0xA2	WCtrl9	On-Demand Calibration on gyroscope

5.9.5 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 0x04 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 0x05 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). The device will direct the FIFO data to the FIFO_DATA register 0x17 until the FIFO is empty. Then the host must set FIFO_rd_mode to 0, which will cause the INT2 to be de-asserted.

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 combination of resistors as shown below:

aux_rpu_dis: CAL1_L bit[0], SDX, SCX, RESV-NC(Pin 10)
icm_rpu_dis: CAL1_L bit[1], SDX
cs_rpu_dis: CAL1_L bit[2], CS
ics_rpu_dis: CAL1_L bit[3], SCL, SDA

The host writes the appropriate CAL1_L bit by issuing a WCtrl9 command with 0x11.

CTRL_CMD_AHB_CLOCK_GATING

When locking Mechanism is set (CTRL7.bit7 == 1(syncSmpl)), the CTRL_CMD_AHB_CLOCK_GATING should also be disabled to guarantee the locking mechanism of data reading, to prevent the possible misalignment.

CTRL_CMD_ON_DEMAND_CALIBRATION

This CTRL9 Command enables host to recalibrate the gyro sensitivity from time to time. The host must disable all the sensors by write 0x00 to CTRL7 first and then start the CTRL9 command process. During which, it is not necessary to place the device in quiet. The recalibrated parameters will be applied to the sensor data afterwards and will be lost if a power on reset or soft reset is implemented.

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 section5.9).*

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

INT1 can be used for motion detection event interrupt if CTRL8.bit is configured to 1, this bit will influence the any/no/sig-motion, pedometer, tap detection interrupt.

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***).***

INT2 can be used for motion detection event interrupt if CTRL8.bit is configured to 0, this bit will influence the any/no/sig-motion, pedometer, tap detection interrupt. The source of interrupts will act with below interrupt in logic-OR.

The following indicates when INT2 will be asserted:

Register-Read Mode (FIFO Bypass Mode)

In Register-Read mode the accelerometer and gyroscope 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.

<u>With syncSmpl = 0</u> (refer to Table 26, 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.

<u>With syncSmpl = 1</u> (refer to Table 26, 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.

<u>**FIFO Enabled Mode**</u> ***(****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.

<u>**Accelerometer and Gyroscope Self Test Modes**</u> *(see Section* 11*)*

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 34 and are shown in Figure 11; they may be configured using the control (CTRL) registers.

Table 34. 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.
Normal Accel Only	Device configured as an accelerometer only.	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR !=11xx
Low Power Accel Only	Device configured in low power accelerometer mode.	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR =11xx
Snooze Gyro	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
Gyro Only	Device configured as a gyroscope only.	CTRL7 gSN=0, aEN =0, gEN =1, mEN =0
Mag Only	Device configured as a magnetometer only.	CTRL7 aEN =0, gEN =0, mEN =1
Accel + Mag	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
Accel + Gyro (IMU)	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
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 gSN=0, aEN =1, gEN =1, mEN =1 CTRL2 aODR != 11xx
Accel + Snooze Gyro	Accelerometer and gyroscope snooze are enabled. Only accelerometer data is available.	CTRL7 gSN=1, aEN =1, gEN =1, mEN =0 CTRL2 aODR != 11xx
Accel + Mag + Snooze Gyro	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
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 5.9.5 and see Section 9, Wake on Motion (WoM)	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR = 11xx

Table 34 Operating Modes (Continued)

Mode	Description	Suggested Configuration
Sensor Modes		
Reset	Software reset asserted	
No Power	VDDIO and VDD low	
AttitudeEngine Modes		
6DOF AttitudeEngine Mode	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
9DOF AttitudeEngine Mode	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)
Motion On Demand Mode	This mode allows Host to sample AttitudeEngine data asynchronously by polling.	CTRL7 aEN = 1, gEN = 1, sEN = 1 CTRL6 sMOD = 1

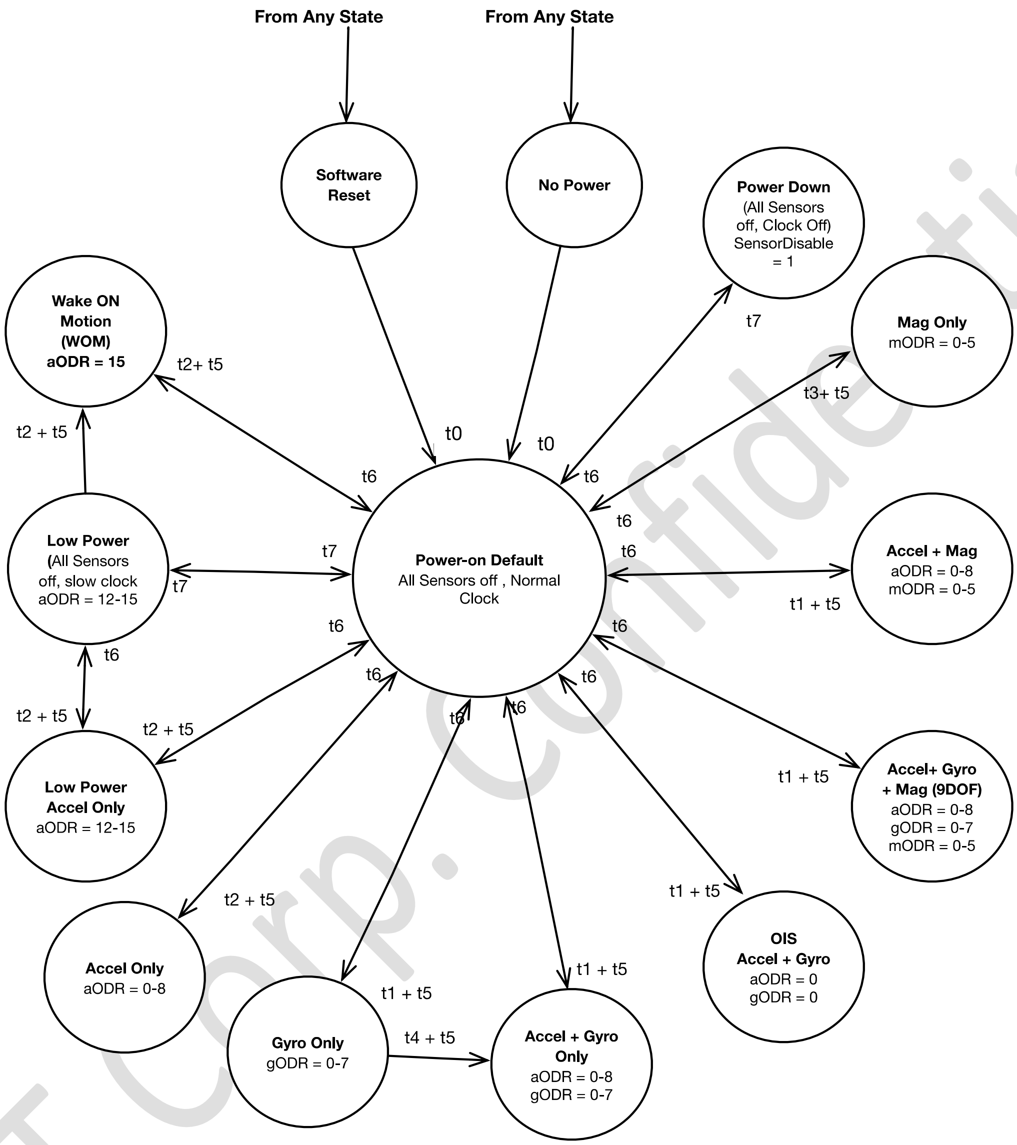


Figure 11. Operating Mode Transition Diagram

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 34 and as shown in Figure 11. 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 150ms 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 and accelerometer 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.

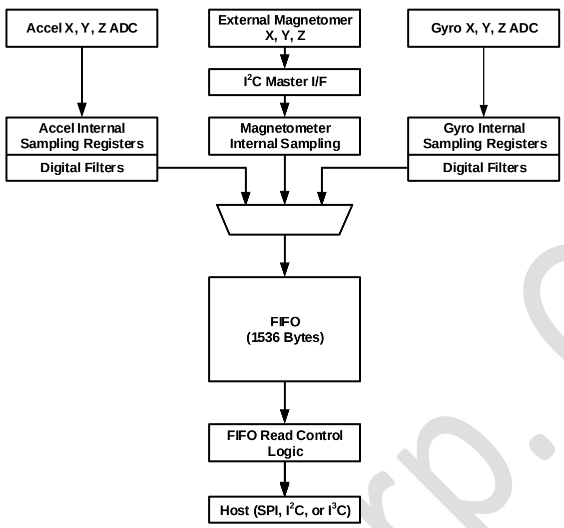


Figure 12. FIFO Data Flow

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. 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 35. FIFO Registers Description

Register Name			
FIFO_WTM_TH		**FIFO Watermark Threshold. Register Address: 19 (0x13)**	
Bits	**Name**	**Default**	**Description**
7:0	FIFO_wtm_th	1’b0	Set watermark level, in ODRs.
FIFO_CTRL		**Configure FIFO. Register Address: 20 (0x14)**	
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 8.1 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_SMPL_CNT		**FIFO Sample Count. Register Address: 21 (0x15)**	
Bits	**Name**	**Default**	**Description**
7:0	fifo_smpl_cnt_lsb	8’h00	The LS 8 bits of FIFO sample count, in bytes.
FIFO_STATUS		**FIFO Status. Register Address: 22 (0x16)**	
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.
FIFO_DATA		**FIFO Data Register. Register Address: 23 (0x17)**	
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 5.9.5 CTRL9 Commands in Detail).

Table 36. 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 13.

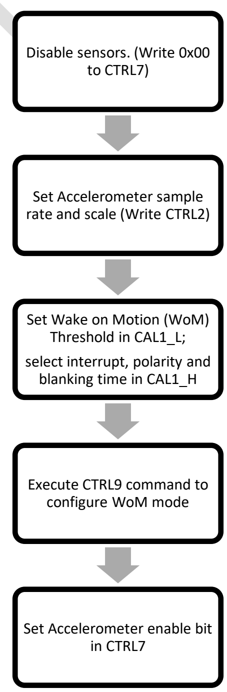


Figure 13. WoM Configuration Commands and Sequence

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 36.

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 36, Registers used for WoM) and execute the WoM configuration CTRL9 command (see write-up for CTRL_CMD_WRITE_WOM_SETTING in Section 5.9.5 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.

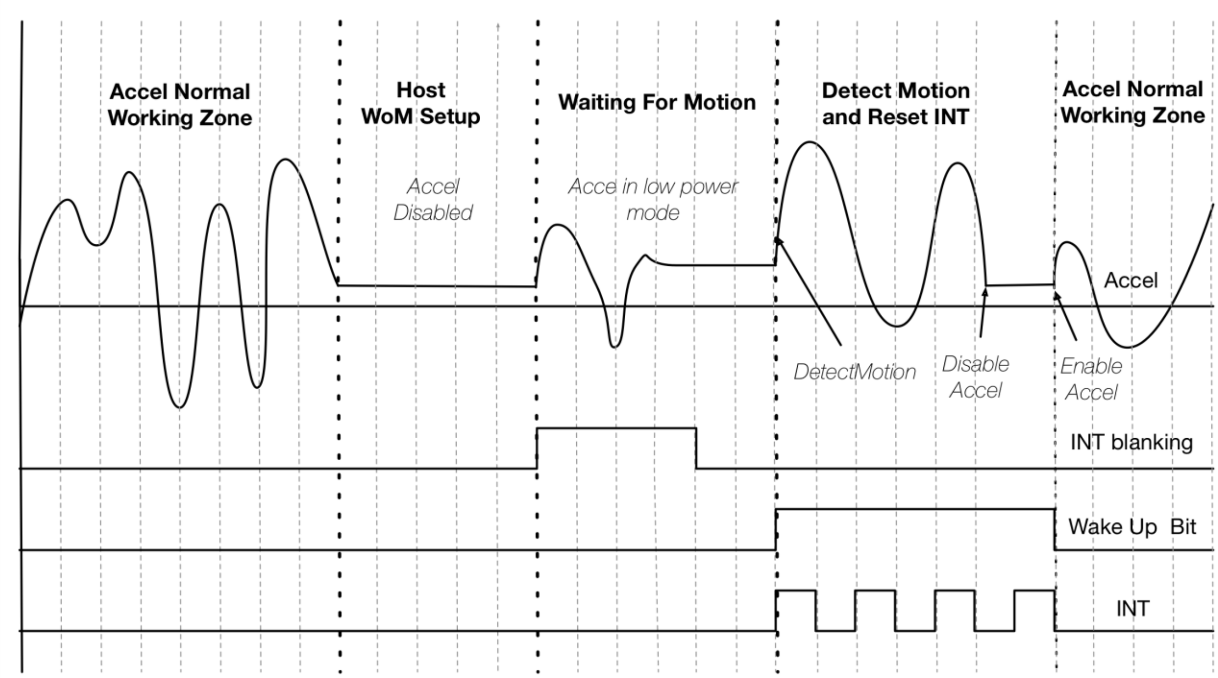


Figure 14. WoM Example Diagram

10 Locking Mechanism

Locking Mechanism function can lock the sensor data and keep the values in data registers after the proper locking process, similar to the "shadow register", which enables host to read the locked data in unlimited delay without the risk of mixing the two consecutive data if reading happens at the time that the new data come and updating to the registers.

10.1 Set Locking Mechanism

The locking Mechanism is set when setting CTRL7.bit7 to "1" (syncSmpl).

Examples:

1- Enabling 6DOF in this mode:

write 0x83 to CTRL7.

2- Enable Accel Only in this mode:

write 0x81 to CTRL7.

After Enabling the sensor(s), the user needs to poll STATUSINT register before reading the sensor data for synchronization, refer to 10.2 for more information.

Note: When using SPI (accel only mode with ODR less than 500Hz), I2C or I3C interfaces (in all ODRs), The user needs to disable the internal AHB clock gating by applying:

1- write 0x01 to CAL1_L register.

2- write 0x12(CTRL_CMD_AHB_CLOCK_GATING) to CTRL9 Register, follow the CTRL9 process.

After disabling the sensor, enable back the clock gating by:

1- write 0x00 to CAL1_L register.

2- write 0x12 to CTRL9 Register (CTRL_CMD_AHB_CLOCK_GATING), follow the CTRL9 process.

10.2 Reading sensor data

An example process of reading sensor data in locking mechanical mode is shown below:

1- Enable the sensor based on description in 10.1 (Disable the AHB clock gating if needed)

2- Poll STATUSINT register:

a- Wait poll delay time.

b- Read STATUSINT register.

If the read value is not (0x01 or 0x03), repeat step 2.

If the value is (0x01 or 0x03) continue onto step 3.

3- Read data:

c- Wait time equals to or higher than data_read_delay (refer to 10.3).

d- At this time, the data will be locked.

e- Read all sensor data.

f- When reading the last byte of data (GZ_H if gyro is enabled, or AZ_H if accel only is enabled), the lock will be cleared.

g- To read next batch of data repeat steps 2 & 3.

4- To disable the sensor write 0x00 to CTRL7. (Enable back the AHB clock gating).

10.3 Data_Read_Delay

When the gyro is enabled the value of data_read_delay is as follow:

ODR setting	ODR(Hz)	data_read_delay (usec)
0	7520	2
1	3760	2
2	1880	4
3	940	6
4	470	12
5	235	12
6	117.5	12
7	58.75	12
8	29.375	12

When the gyro is not enabled (accel only mode) the value of data_read_delay is as follow:

ODR setting	ODR(Hz)	data_read_delay (usec)
3	1000	6
4	500	12
5	250	24
6	125	48
7	62.5	48
8	31.25	48
12	128	40
13	21	100
14	11	200
15	3	270

10.4 On-The-Fly ODR changing

The on-the-fly ODR changing is supported, so host can change the ODR of sensor without disable the sensor.

An example sequence of change ODR without disable the sensor in locking mechanism is shown below:

1- Write CTRL2/CTRL3 to set the ODR's of accelerometer and gyroscope and full scales.

2- Write 0x83 (or 0x82) to CTRL7.

3- Read Sensor Data according 10.2.

4- Changing ODR on the fly:

   a- Write 0x02 (or 0x03) to CTRL7(clear the syncSmpl bit).

   b- Wait 700us.

   c- Clear the lock in case if the data is still locked from previous ODR by reading GZ_H if gyroscope is enabled or AZ_H if accelerometer only is enabled.

   d- Write CTRL2 / CTRL3 with the new ODR's.

   e- Write 0x83 (or 0x82) to CTRL7.

5- Start poll and read Sensor Data using the new ODRs based on 10.2.

6- The new data will be stable in about 3~5 samples, so it is recommended to through away the first several samples at host side.

11 Performing Device Self Test

11.1 Accelerometer Self Test

The accelerometer Self Test is used to determine if the accelerometer is functional and working within acceptable parameters. It is implemented by applying an electrostatic force to actuate each of the three X, Y, and Z axis of the accelerometer. If the accelerometer mechanical structure responds to this input stimulus by sensing at least 200 mg, then the accelerometer can be considered functional within acceptable parameters. 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- Make sure that the sensor is disabled. (CTRL7 = 0x00).

2- Set the bit aST to 1. (CTRL2.bit7 = 1'b1)

The 16g Full Scale is always used for Accel Self Test, regardless to the aFS settings in CTRL2.

The ODR setting in CTRL2 will be used for the Accel Self Test functionality.

3- Wait for QMI8658C to drive INT2 to “1”.

4- Disable the Accel Self Test by clearing aST bit in CTRL2. (CTRL2.bit7 = 1'b0)

5- Wait for QMI8658C drive INT2 back to “0”.

6- Read the Accel Self Test result:

X channel: dVX_L and dVX_H (registers 81 and 82).

Y channel: dVY_L and dVY_H (registers 83 and 84).

Z channel: dVZ_L and dVZ_H (registers 85 and 86).

Read the 16 bits result in format (signed 5.11) from the according registers of X, Y & Z channels.

If the absolute results of all three axes are higher than 200mg, the accelerometer can be consider functional. Otherwise, the accelerometer cannot be consider functional.

Here is an example of running accelerometer Self Test.

1- Write 0x00 to CTRL7.

2- Wait 1 msec.

3- Write 0x83 to CTRL2 (enable the Accel Self Test, and set 1KHz ODR).

4- Wait for INT2 is set to “1”.

5- Write 0x03 to CTRL2 (disable the Accel Self Test).

6- Wait for INT2 to be cleared to “0”.

7- Read final result from registers 81 up to 86 and compare.

11.2 Gyroscope Self Test

The gyroscope Self Test is used to determine if the gyroscope is functional and working within acceptable parameters. It is implemented 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 gyroscope output is greater than 300dps for each axis, the gyroscope can be considered as 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- Make sure that the sensor is disabled. (CTRL7 = 0x00).

2- Set the bit gST to 1. (CTRL3.bit7 = 1'b1).

The 2048dps Full Scale and 1 KHz ODR is always used for gyroscope Self Test. The Full Scale and ODR portion in CTRL3 are ignored.

3- Wait for QMI8658C to drive INT2 to “1”.

4- Disable the Gyro self test by clearing gST bit in CTRL3. (CTRL2.bit7 = 1'b0)

5- Wait for QMI8658C drive INT2 back to “0”.

6- Read the Gyro Self Test result:

X channel: dVX_L and dVX_H (registers 81 and 82).

Y channel: dVY_L and dVY_H (registers 83 and 84).

Z channel: dVZ_L and dVZ_H (registers 85 and 86).

Read the 16 bits result in format (signed 12.4) from the according registers of X, Y & Z channels.

If the absolute results of all three axes are higher than 300dps, the gyroscope can be considered functional. Otherwise, the gyroscope cannot be considered functional.

Here is an example of running gyroscope Self Test.

1- Write 0x00 to CTRL7.

2- Wait 1 msec.

3- Write 0x83 to CTRL3 (enable the gyroscope Self Test).

4- Wait for INT2 is set to “1”.

5- Write 0x03 to CTRL3(disable the gyroscope Self Test).

6- Wait for INT2 to be cleared to “0”.

7- Read final result from registers 81 up to 86 and compare.

12 Host Serial Interface

QMI8658C Host Serial Interface supports MIPI I3C, I^2C 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 26).*

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 15 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 15. SPI Address and Data Format

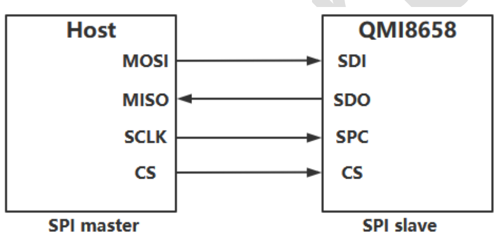


Figure 16. Typical SPI 4-Wire *Multi-Slave*

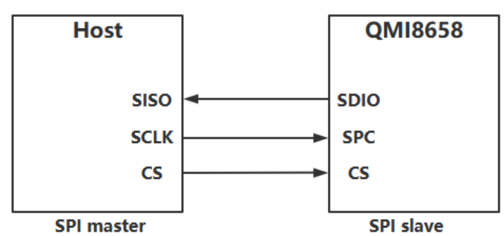
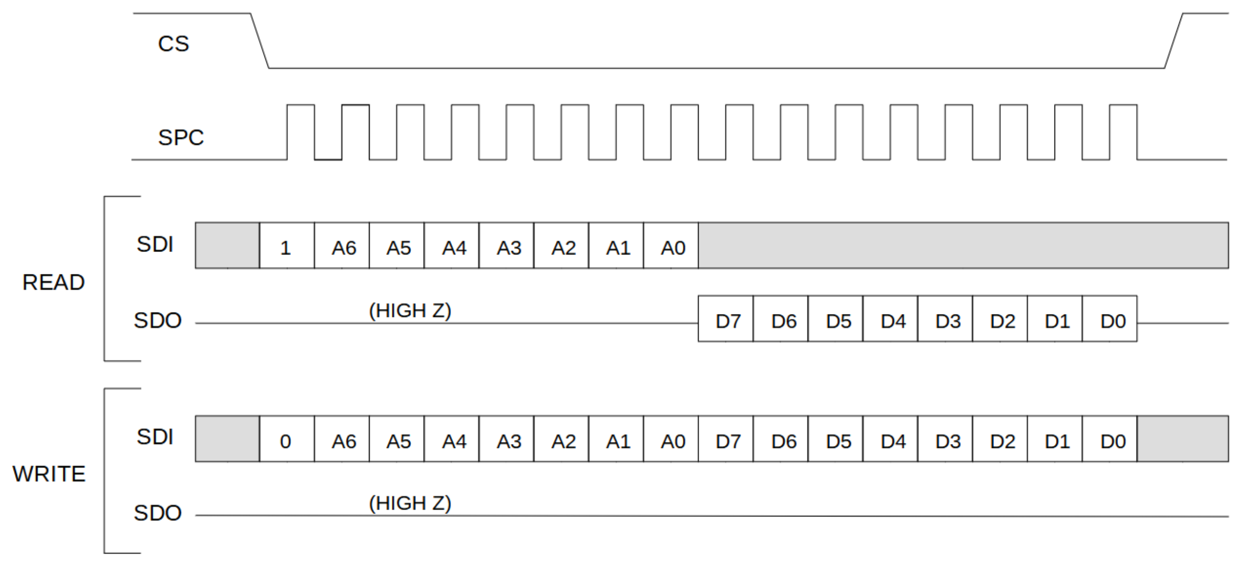


Figure 17. Typical SPI 3-Wire Multi-Slave

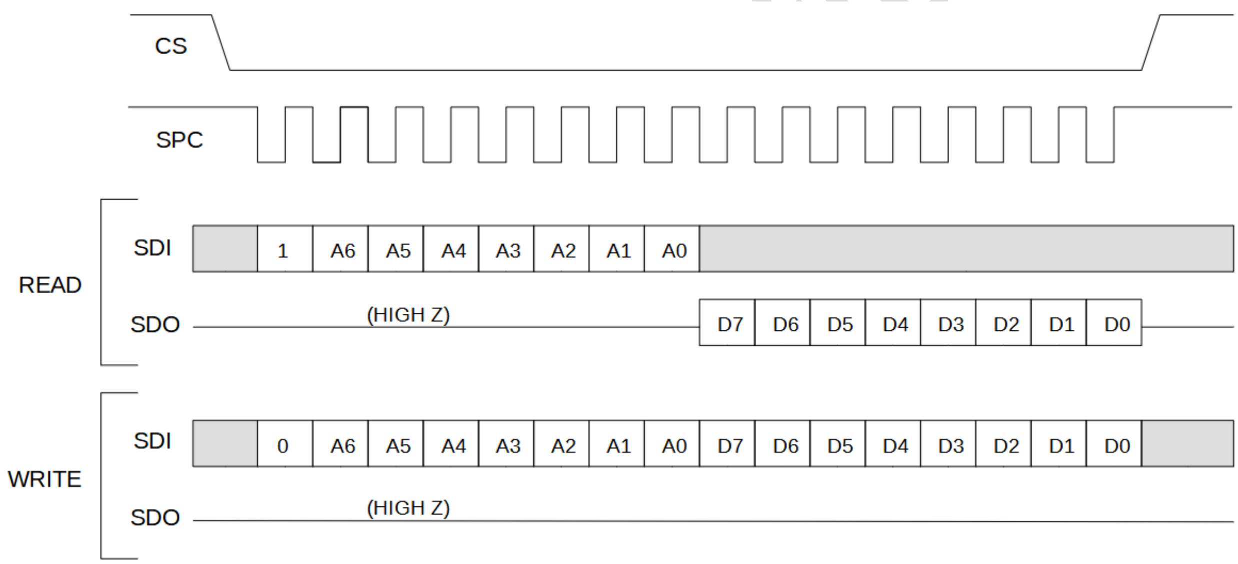
In a typical SPI Master/Slave configuration the SPI master shares the SPI clock (SPC), the serial data input (SDI), and the Serial Data Output (SDO) with all the connected SPI slave devices. Unique Chip Select (CS) lines connect each SPI slave to the master.

Figure 16 and Figure 17 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 18 and Figure 19 illustrate the waveforms for both 4-wire and 3-wire SPI read and write transactions. Note that CS is active during the entire transaction.

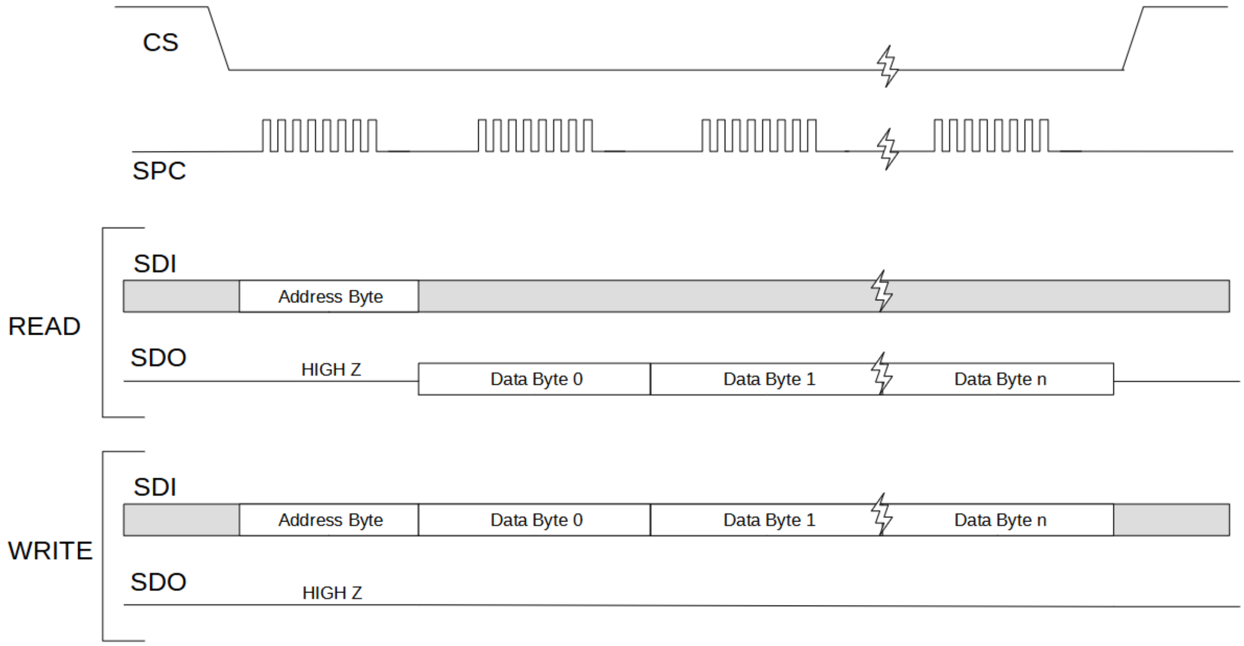


SPI : Mode 0

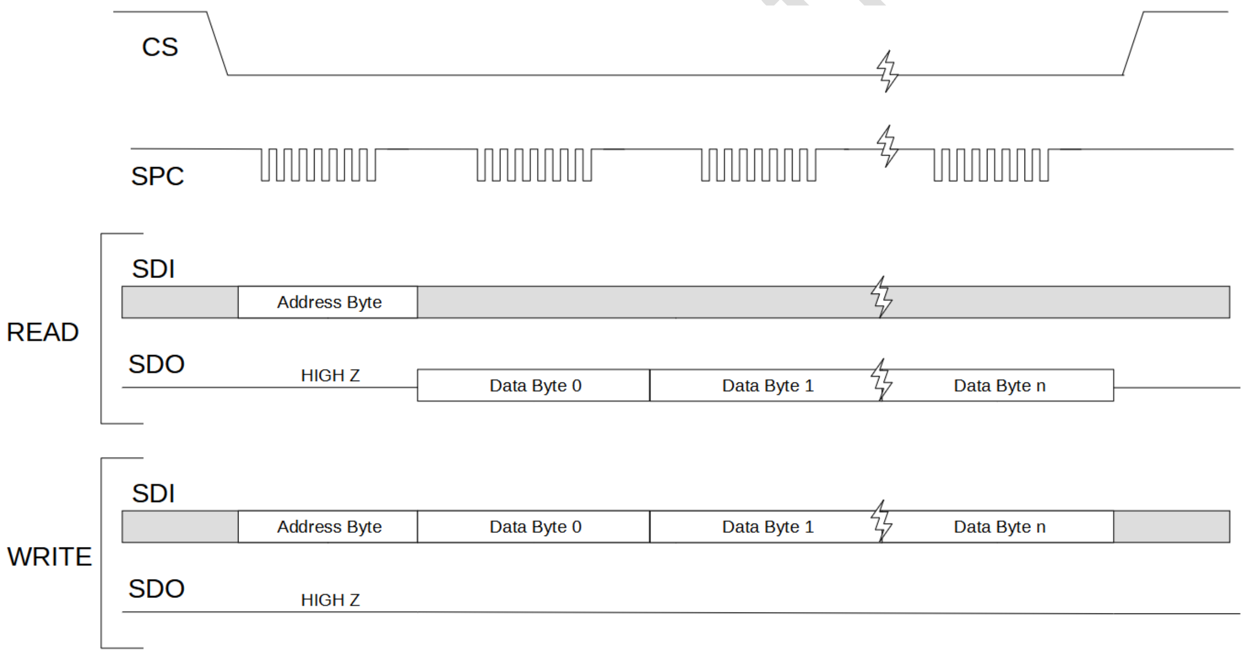


SPI : Mode 3

Figure 18. SPI 4-Wire Single Byte Read and Write (Mode 0 and Mode 3)



SPI : Mode 0



SPI : Mode 3

Figure 19. SPI 4-Wire Multi-Byte Read and Write Transactions

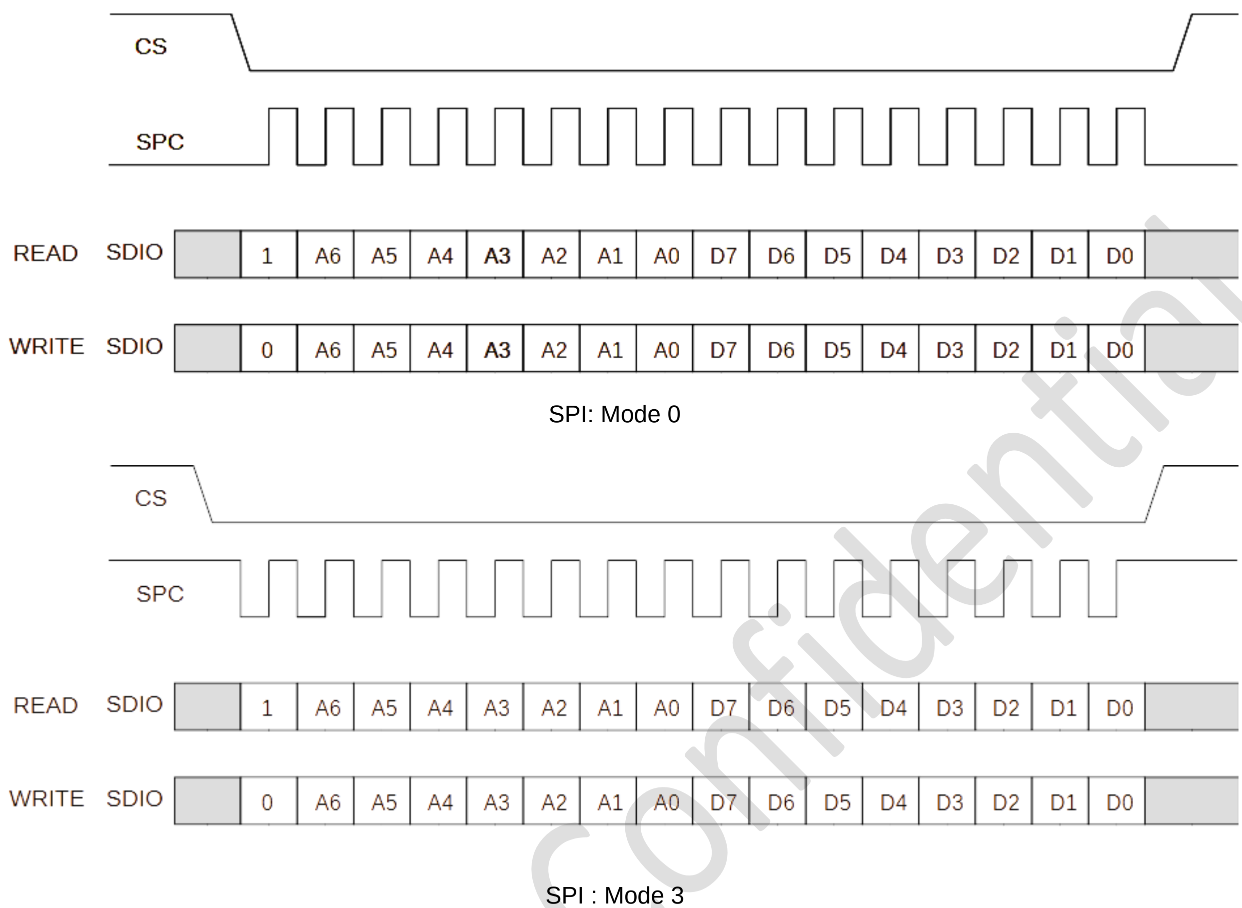
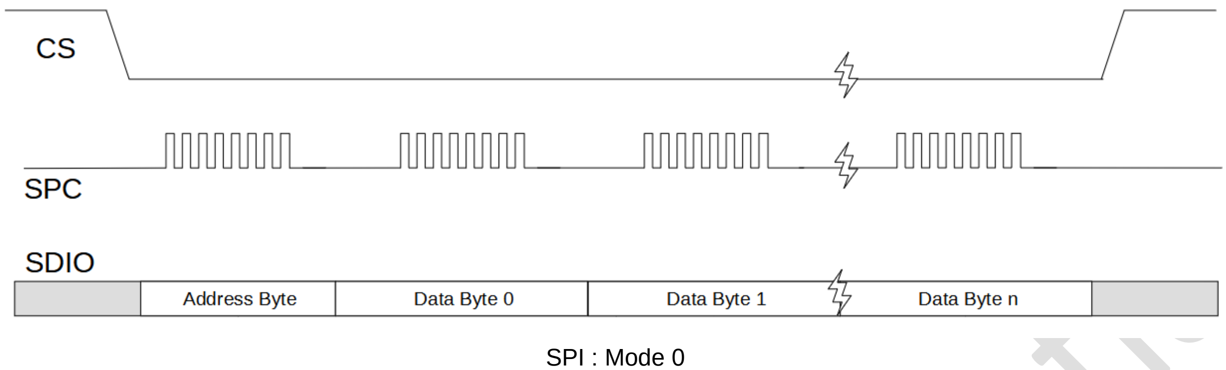


Figure 20. SPI 3-Wire Single Byte Read and Write Transactions



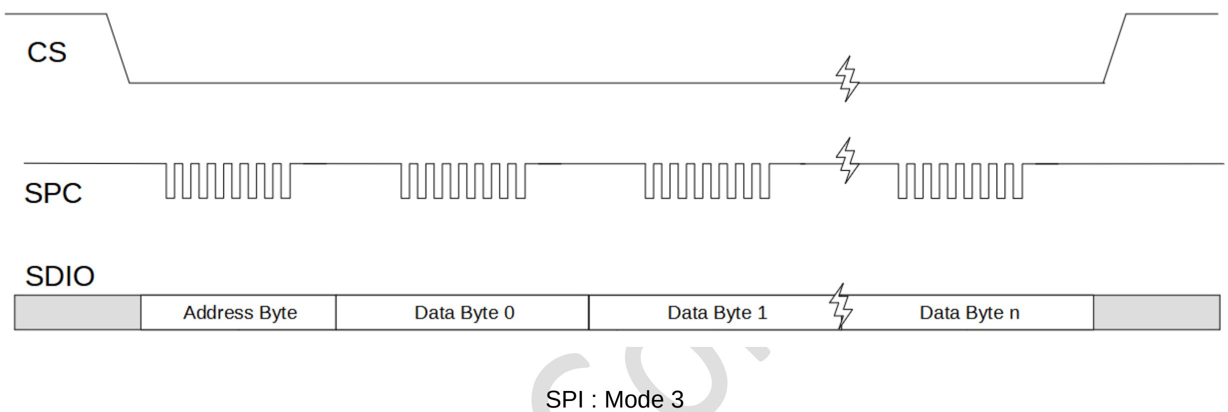


Figure 21. SPI 3-Wire Multi-Byte Read and Write Transactions

12.1.1 SPI Timing Characteristics

The typical operating conditions for the SPI interface are provided in Table 37. Please refer to Table 5 for the V_{IL}, V_{IH}, V_{OL}, V_{OH} definition to define the rising and falling edge condition of the timing symbols.

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

Table 37. 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

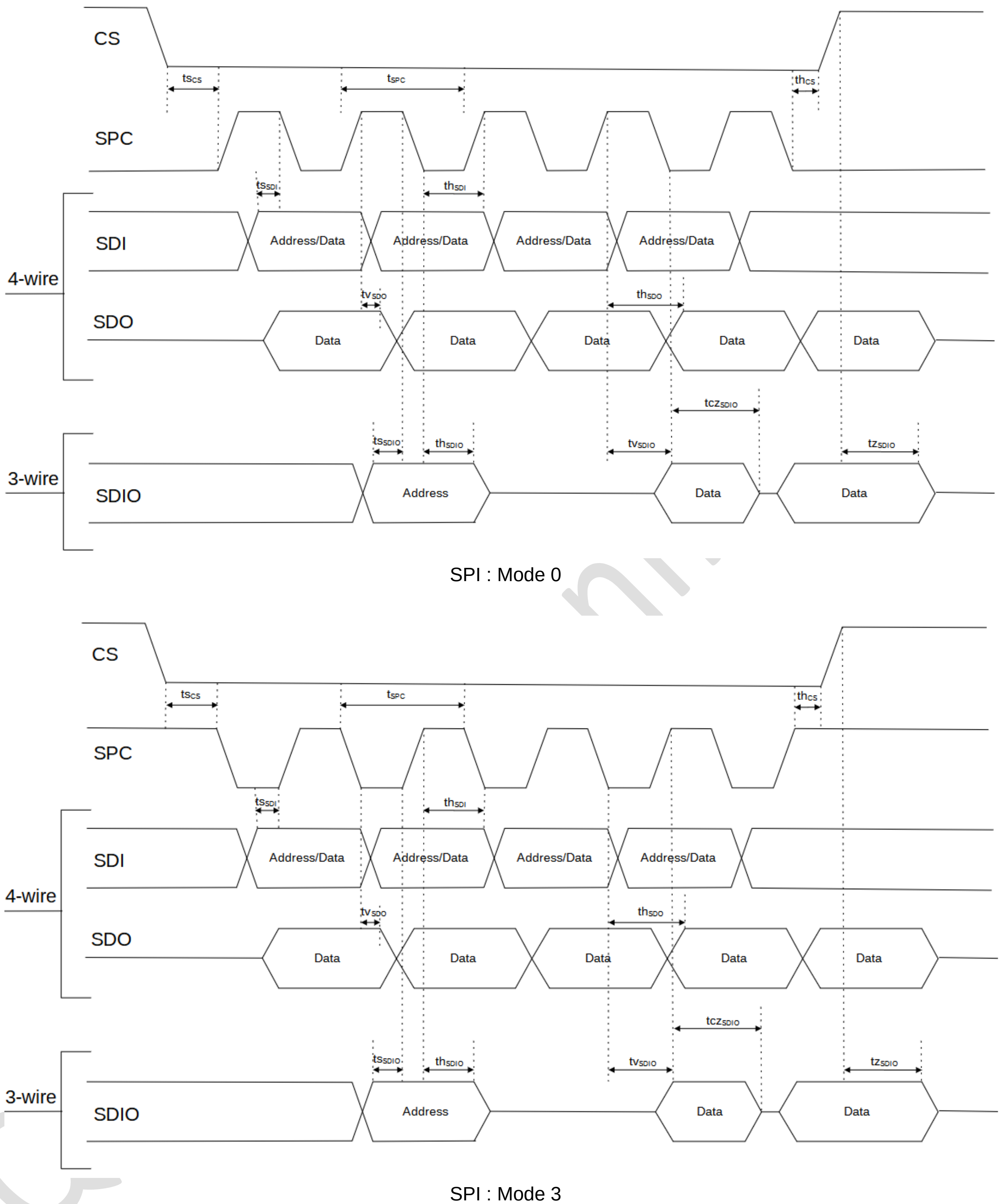


Figure 22. Timing Characteristics for SPI 3- and 4-Wire Interfaces

12.2 I²C Interface

Table 38 provides the I²C interface timing characteristics while Figure 23 and Figure 24 illustrate the I²C timing for both fast and standard modes, respectively. Please refer to Table 5 for the V_{IL}, V_{IH}, V_{OL}, V_{OH} definition to define the rising and falling edge condition of the timing symbols.

During the slave device selection phase, the I²C master supplies the 7-bit I²C slave device address to enable the QMI8658C. When SA0 is pulled down externally, the 7-bit device address becomes 0x6B (0b1101011). In case of a slave device ID conflict, SA0 may be used to change bit-0 of the device address. The 7-bit device address for the QMI8658C is 0x6A (0b1101010) if SA0 is pulled up or left unconnected (internally there is a weak pull-up of 200KΩ).

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 38. I²C Timing Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{SCL}	SCL Clock Frequency		0		400	KHz
t_{BUF}	Bus-Free Time between STOP and START Conditions		1300			ns
$t_{HD;STA}$	START or Repeated START Hold Time		600			ns
t_{LOW}	SCL LOW Period		1300			ns
t_{HIGH}	SCL HIGH Period		600			ns
$t_{SU;STA}$	Repeated START Setup Time		600			ns
$t_{SU;DAT}$	Data Setup Time		100			ns
$t_{HD;DAT}$	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		600			ns

Note:

14. C_B is the bus capacitance.

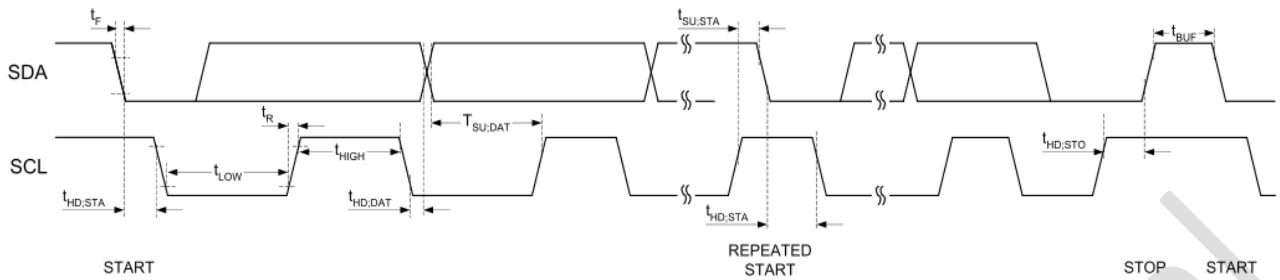
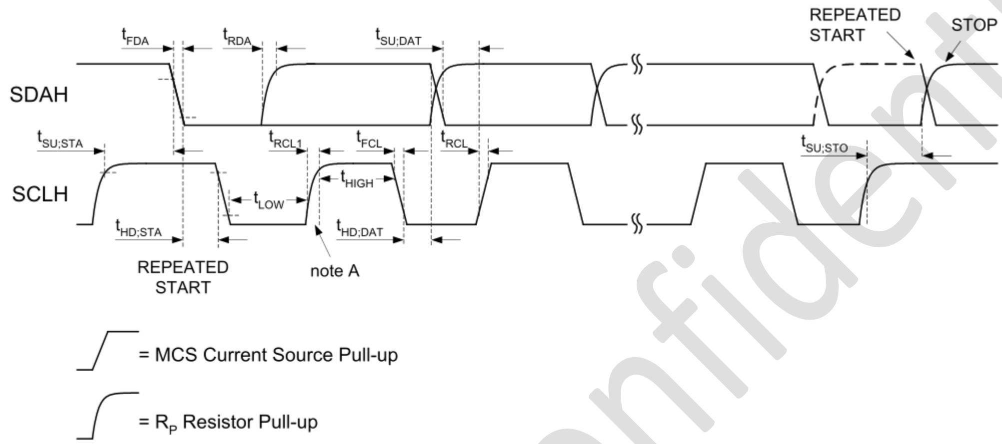


Figure 23. I²C Standard Mode Interface Timing



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

Figure 24. 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

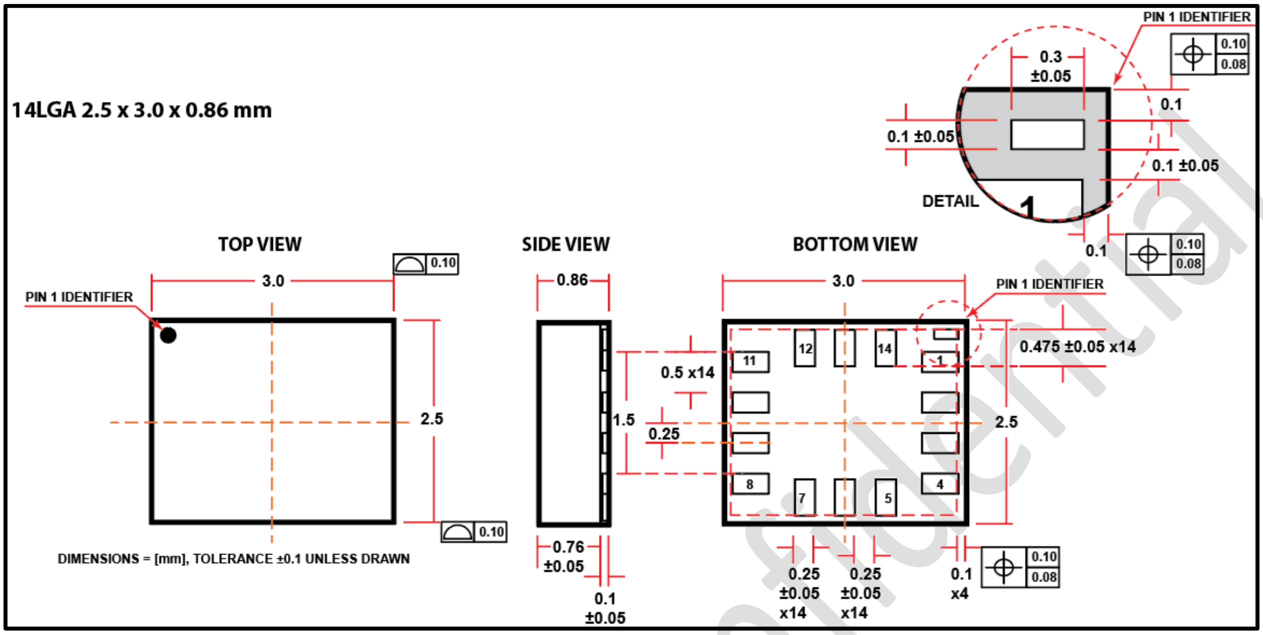
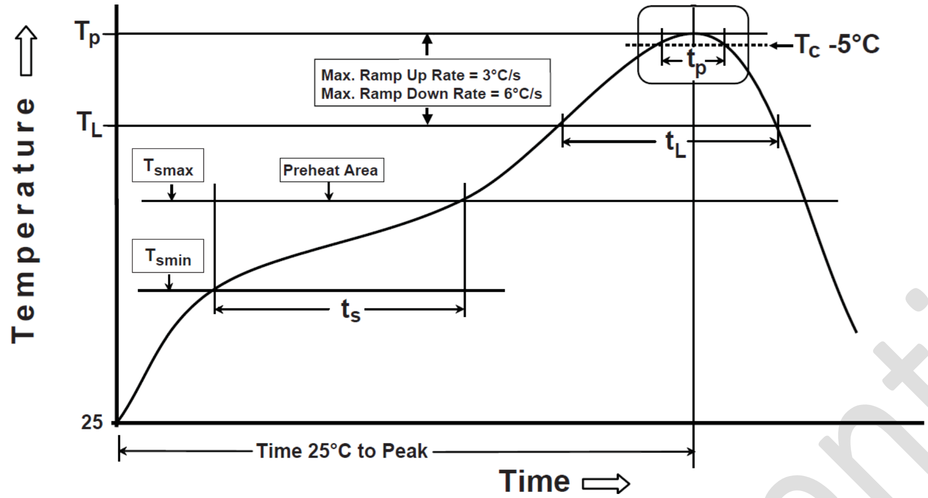


Figure 25. 14 Pin LGA 2.5 x 3.0 x 0.86 mm Package

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 26. 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 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
0.7	17 May, 2021	Updated the pin name and function name map, typical SPI connections, soft reset, Self Test, On-Demand Calibration, I2C timing parameter table, ADDR_AI, BE, VDDIO rising limitation, recommended I2C pull-up resistance
0.8	10 Sep, 2021	Added the maximum limitation of VIH, updated FIFO read command and sequence, updated ODR & filter bandwidth configurations, updated CTRL2, CTRL3, CTRL4, CTRL5 descriptions, deleted descriptions of magnetometer, updated Electro-Mechanical Specifications, updated the internal block diagram & interface operating modes, deleted the specifications, registers, and application diagrams that relative to I2CM interface, updated the Features, Descriptions & Applications, updated the marking information, updated the disabling of the internal pull-up resistors in IOs,
0.9	10 Jan, 2022	updated the INT1/INT2 enable bit in CTRL1, updated Wake on Motion, added locking mechanism

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