

## World's Lowest Power 9-Axis MEMS MotionTracking™ Device

### GENERAL DESCRIPTION

The ICM-20948 is the world's lowest power 9-axis MotionTracking device that is ideally suited for Smartphones, Tablets, Wearable Sensors, and IoT applications.

- 3-axis gyroscope, 3-axis accelerometer, 3-axis compass, and a Digital Motion Processor™ (DMP™) in a 3 mm x 3 mm x 1 mm (24-pin QFN) package
- DMP offloads computation of motion processing algorithms from the host processor, improving system power performance
- Software drivers are fully compliant with Google's latest Android release
- EIS FSYNC support

ICM-20948 supports an auxiliary I<sup>2</sup>C interface to external sensors, on-chip 16-bit ADCs, programmable digital filters, an embedded temperature sensor, and programmable interrupts. The device features an operating voltage range down to 1.71V. Communication ports include I<sup>2</sup>C and high speed SPI at 7 MHz.

Note: ICM-20948 VDDIO range is 1.71V to 1.95V, different than the MPU-9250 9-axis device.

### ORDERING INFORMATION

| PART       | TEMP RANGE     | PACKAGE    |
|------------|----------------|------------|
| ICM-20948† | -40°C to +85°C | 24-Pin QFN |

†Denotes RoHS and Green-Compliant Package

### BLOCK DIAGRAM



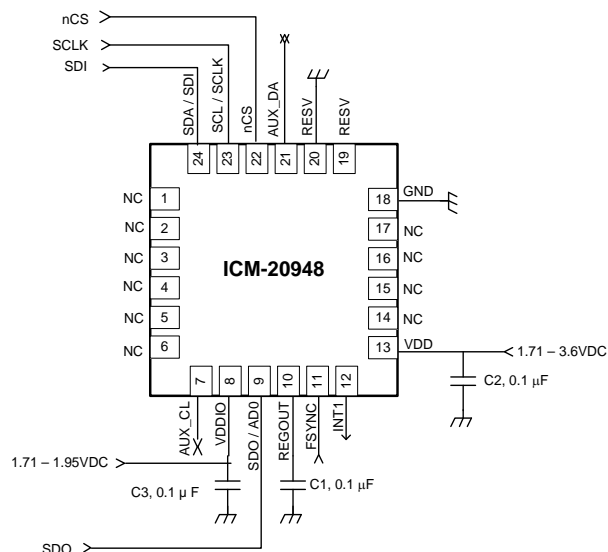
### APPLICATIONS

- Smartphones and Tablets
- Wearable Sensors
- IoT Applications

### FEATURES

- Lowest Power 9-Axis Device at 2.5 mW
- 3-Axis Gyroscope with Programmable FSR of  $\pm 250$  dps,  $\pm 500$  dps,  $\pm 1000$  dps, and  $\pm 2000$  dps
- 3-Axis Accelerometer with Programmable FSR of  $\pm 2g$ ,  $\pm 4g$ ,  $\pm 8g$ , and  $\pm 16g$
- 3-Axis Compass with a wide range to  $\pm 4900$   $\mu$ T
- Onboard Digital Motion Processor (DMP)
- Android support
- Auxiliary I<sup>2</sup>C interface for external sensors
- On-Chip 16-bit ADCs and Programmable Filters
- 7 MHz SPI or 400 kHz Fast Mode I<sup>2</sup>C
- Digital-output temperature sensor
- VDD operating range of 1.71V to 3.6V
- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

### TYPICAL OPERATING CIRCUIT



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## **1 GENERAL DESCRIPTION**

### **1.1 PURPOSE AND SCOPE**

This document is a preliminary data sheet, providing a description, specifications, and design related information on the ICM-20948 MotionTracking device.

For references to register map and descriptions of individual registers, please refer to the ICM-20948 Register Map and Register Descriptions document.

### **1.2 PRODUCT OVERVIEW**

The ICM-20948 is a multi-chip module (MCM) consisting of two dies integrated into a single QFN package. One die houses a 3-axis gyroscope, a 3-axis accelerometer, and a Digital Motion Processor™ (DMP). The other die houses the AK09916 3-axis magnetometer from Asahi Kasei Microdevices Corporation. The ICM-20948 is a 9-axis MotionTracking device all in a small 3x3x1mm QFN package. The device supports the following features:

- FIFO of size 512 bytes (FIFO size will vary depending on DMP feature-set)
- Runtime Calibration
- Enhanced FSYNC functionality to improve timing for applications like EIS

ICM-20948 devices, with their 9-axis integration, on-chip DMP, and run-time calibration firmware, enable manufacturers to eliminate the costly and complex selection, qualification, and system level integration of discrete devices, guaranteeing optimal motion performance for consumers.

The gyroscope has a programmable full-scale range of  $\pm 250$  dps,  $\pm 500$  dps,  $\pm 1000$  dps, and  $\pm 2000$  dps. The accelerometer has a user-programmable accelerometer full-scale range of  $\pm 2g$ ,  $\pm 4g$ ,  $\pm 8g$ , and  $\pm 16g$ . Factory-calibrated initial sensitivity of both sensors reduces production-line calibration requirements.

Other key features include on-chip 16-bit ADCs, programmable digital filters, an embedded temperature sensor, and programmable interrupts. The device features I<sup>2</sup>C and SPI serial interfaces, a VDD operating range of 1.71V to 3.6V, and a separate digital IO supply, VDDIO from 1.71V to 1.95V.

Communication with all registers of the device is performed using I<sup>2</sup>C at up to 100 kHz (standard-mode) or up to 400 kHz (fast-mode), or SPI at up to 7 MHz.

By leveraging its patented and volume-proven CMOS-MEMS fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level bonding, InvenSense has driven the package size down to a footprint and thickness of 3 mm x 3 mm x 1 mm (24-pin QFN), to provide a very small yet high-performance, low-cost package. The device provides high robustness by supporting 20,000g shock reliability.

### **1.3 APPLICATIONS**

- Smartphones and Tablets
- Wearable Sensors
- IoT Applications
- Drones

## **2 FEATURES**

### **2.1 GYROSCOPE FEATURES**

The triple-axis MEMS gyroscope in the ICM-20948 includes the following features:

- Digital-output X-, Y-, and Z-axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of  $\pm 250$  dps,  $\pm 500$  dps,  $\pm 1000$  dps, and  $\pm 2000$  dps, and integrated 16-bit ADCs
- User-selectable ODR; User-selectable low pass filters
- Self-test

### **2.2 ACCELEROMETER FEATURES**

The triple-axis MEMS accelerometer in ICM-20948 includes the following features:

- Digital-output X-, Y-, and Z-axis accelerometer with a programmable full scale range of  $\pm 2g$ ,  $\pm 4g$ ,  $\pm 8g$ , and  $\pm 16g$ , and integrated 16-bit ADCs
- User-selectable ODR; User-selectable low pass filters
- Wake-on-motion interrupt for low power operation of applications processor
- Self-test

### **2.3 MAGNETOMETER FEATURES**

The triple-axis MEMS magnetometer in ICM-20948 includes a wide range of features:

- 3-axis silicon monolithic Hall-effect magnetic sensor with magnetic concentrator
- Wide dynamic measurement range and high resolution with lower current consumption.
- Output data resolution of 16-bits
- Full scale measurement range is  $\pm 4900 \mu T$
- Self-test function with internal magnetic source to confirm magnetic sensor operation on end products

### **2.4 DMP FEATURES**

The DMP in ICM-20948 includes the following capabilities:

- Offloads computation of motion processing algorithms from the host processor. The DMP can be used to minimize power, simplify timing, simplify the software architecture, and save valuable MIPS on the host processor for use in applications.
- The DMP enables ultra-low power run-time and background calibration of the accelerometer, gyroscope, and compass, maintaining optimal performance of the sensor data for both physical and virtual sensors generated through sensor fusion. This enables the best user experience for all sensor enabled applications for the lifetime of the device.
- DMP features simplify the software architecture resulting in quicker time to market.
- DMP features are OS, Platform, and Architecture independent, supporting virtually any AP, MCU, or other embedded architecture.

### **2.5 ADDITIONAL FEATURES**

The ICM-20948 includes the following additional features:

- I<sup>2</sup>C at up to 100 kHz (standard-mode) or up to 400 kHz (fast-mode) or SPI at up to 7 MHz for communication with registers
- Auxiliary master I<sup>2</sup>C bus for reading data from external sensors (e.g. magnetometer)
- Digital-output temperature sensor
- 20,000g shock tolerant
- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

### 3 ELECTRICAL CHARACTERISTICS

#### 3.1 GYROSCOPE SPECIFICATIONS

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

**NOTE:** All specifications apply to Low-Power Mode and Low-Noise Mode, unless noted otherwise

| PARAMETER   | CONDITIONS  | MIN | TYP   | MAX    | UNITS     | NOTES |
|---|---|-----|-------|--------|-----------|-------|
| <b>GYROSCOPE SENSITIVITY</b>                        |   |     |       |        |           |       |
| Full-Scale Range                                    | GYRO_FS_SEL=0                                       |     | ±250  |        | dps       | 1     |
|   | GYRO_FS_SEL=1                                       |     | ±500  |        | dps       | 1     |
|   | GYRO_FS_SEL=2                                       |     | ±1000 |        | dps       | 1     |
|   | GYRO_FS_SEL=3                                       |     | ±2000 |        | dps       | 1     |
| Gyroscope ADC Word Length                           |   |     | 16    |        | bits      | 1     |
| Sensitivity Scale Factor                            | GYRO_FS_SEL=0                                       |     | 131   |        | LSB/(dps) | 1     |
|   | GYRO_FS_SEL=1                                       |     | 65.5  |        | LSB/(dps) | 1     |
|   | GYRO_FS_SEL=2                                       |     | 32.8  |        | LSB/(dps) | 1     |
|   | GYRO_FS_SEL=3                                       |     | 16.4  |        | LSB/(dps) | 1     |
| Sensitivity Scale Factor Tolerance                  | 25°C  |     | ±1.5  |        | %         | 2     |
| Sensitivity Scale Factor Variation Over Temperature | -40°C to +85°C                                      |     | ±3    |        | %         | 2     |
| Nonlinearity  | Best fit straight line; 25°C                        |     | ±0.1  |        | %         | 2, 3  |
| Cross-Axis Sensitivity                              |   |     | ±2    |        | %         | 2, 3  |
| <b>ZERO-RATE OUTPUT (ZRO)</b>                       |   |     |       |        |           |       |
| Initial ZRO Tolerance                               | 25°C (Component-level)                              |     | ±5    |        | dps       | 2     |
| ZRO Variation Over Temperature                      | -40°C to +85°C                                      |     | ±0.05 |        | dps/°C    | 2     |
| <b>GYROSCOPE NOISE PERFORMANCE (GYRO_FS_SEL=0)</b>  |   |     |       |        |           |       |
| Noise Spectral Density                              | Based on Noise Bandwidth = 10 Hz                    |     | 0.015 |        | dps/√Hz   | 2     |
| <b>GYROSCOPE MECHANICAL FREQUENCIES</b>             |   | 25  | 27    | 29     | kHz       | 2     |
| <b>LOW PASS FILTER RESPONSE</b>                     | Programmable Range                                  | 5.7 |       | 197    | Hz        | 1, 3  |
| <b>GYROSCOPE START-UP TIME</b>                      | From Full-Chip Sleep mode                           |     | 35    |        | ms        | 2, 3  |
| <b>OUTPUT DATA RATE</b>                             | Low-Power Mode                                      | 4.4 |       | 562.5  | Hz        | 1     |
|   | Low-Noise Mode<br>GYRO_FCHOICE=1;<br>GYRO_DLPFCFG=x | 4.4 |       | 1.125k | Hz        |       |
|   | Low-Noise Mode<br>GYRO_FCHOICE=0;<br>GYRO_DLPFCFG=x |     |       | 9k     | Hz        |       |
|   |   |     |       |        |           |       |

**Table 1. Gyroscope Specifications**

**NOTES:**

1. Guaranteed by design.
2. Derived from validation or characterization of parts, not guaranteed in production.
3. Low-noise mode specification.

### 3.2 ACCELEROMETER SPECIFICATIONS

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

**NOTES:** All specifications apply to Low-Power Mode and Low-Noise Mode, unless noted otherwise

| PARAMETER                              | CONDITIONS  | MIN  | TYP    | MAX    | UNITS  | NOTES |
|--|---|------|--------|--------|--------|-------|
| <b>ACCELEROMETER SENSITIVITY</b>       |   |      |        |        |        |       |
| Full-Scale Range                       | ACCEL_FS=0  |      | ±2     |        | G      | 1     |
|  | ACCEL_FS=1  |      | ±4     |        | G      | 1     |
|  | ACCEL_FS=2  |      | ±8     |        | G      | 1     |
|  | ACCEL_FS=3  |      | ±16    |        | G      | 1     |
| ADC Word Length                        | Output in two's complement format                     |      | 16     |        | Bits   | 1     |
| Sensitivity Scale Factor               | ACCEL_FS=0  |      | 16,384 |        | LSB/g  | 1     |
|  | ACCEL_FS=1  |      | 8,192  |        | LSB/g  | 1     |
|  | ACCEL_FS=2  |      | 4,096  |        | LSB/g  | 1     |
|  | ACCEL_FS=3  |      | 2,048  |        | LSB/g  | 1     |
| Initial Tolerance                      | Component-level                                       |      | ±0.5   |        | %      | 2     |
| Sensitivity Change vs. Temperature     | -40°C to +85°C ACCEL_FS=0                             |      | ±0.026 |        | %/°C   | 2     |
| Nonlinearity                           | Best Fit Straight Line                                |      | ±0.5   |        | %      | 2, 3  |
| Cross-Axis Sensitivity                 |   |      | ±2     |        | %      | 2, 3  |
| <b>ZERO-G OUTPUT</b>                   |   |      |        |        |        |       |
| Initial Tolerance                      | Component-level, all axes                             |      | ±25    |        | mg     | 2     |
| Initial Tolerance                      | Board-level, all axes                                 |      | ±50    |        | mg     | 2     |
| Zero-G Level Change vs. Temperature    | 0°C to +85°C  |      | ±0.80  |        | mg/°C  | 2     |
| <b>ACCELEROMETER NOISE PERFORMANCE</b> |   |      |        |        |        |       |
| Noise Spectral Density                 | Based on Noise Bandwidth = 10 Hz                      |      | 230    |        | µg/√Hz | 2     |
| <b>LOW PASS FILTER RESPONSE</b>        | Programmable Range                                    | 5.7  |        | 246    | Hz     | 1, 3  |
| <b>ACCELEROMETER STARTUP TIME</b>      | From Sleep mode                                       |      | 20     |        | ms     | 2, 3  |
|  | From Cold Start, 1 ms V <sub>DD</sub> ramp            |      | 30     |        | ms     | 2, 3  |
| <b>OUTPUT DATA RATE</b>                | Low-Power Mode  | 0.27 |        | 562.5  | Hz     | 1     |
|  | Low-Noise Mode<br>ACCEL_FCHOICE=1;<br>ACCEL_DLPFCFG=x | 4.5  |        | 1.125k | Hz     |       |
|  | Low-Noise Mode<br>ACCEL_FCHOICE=0;<br>ACCEL_DLPFCFG=x |      |        | 4.5k   | Hz     |       |
|  |   |      |        |        |        |       |

**Table 2. Accelerometer Specifications**

**NOTES:**

1. Guaranteed by design.
2. Derived from validation or characterization of parts, not guaranteed in production.
3. Low-noise mode specification.

### 3.3 MAGNETOMETER SPECIFICATIONS

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

| PARAMETER                       | CONDITIONS | MIN   | TYP   | MAX   | UNITS    | NOTES |
|---------------------------------|------------|-------|-------|-------|----------|-------|
| <b>MAGNETOMETER SENSITIVITY</b> |            |       |       |       |          |       |
| Full-Scale Range                |            |       | ±4900 |       | μT       | 1     |
| Output Resolution               |            |       | 16    |       | bits     | 1     |
| Sensitivity Scale Factor        |            |       | 0.15  |       | μT / LSB | 1     |
| <b>ZERO-FIELD OUTPUT</b>        |            |       |       |       |          |       |
| Initial Calibration Tolerance   |            | -2000 |       | +2000 | LSB      | 2     |
| <b>OTHER</b>                    |            |       |       |       |          |       |
| Output Data Rate                |            |       |       | 100   | Hz       | 1     |

**Table 3. Magnetometer Specifications**

**NOTES:**

1. Guaranteed by design.
2. Derived from validation or characterization of parts, not guaranteed in production.

### 3.4 ELECTRICAL SPECIFICATIONS

#### D.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

| PARAMETER   | CONDITIONS   | MIN  | TYP  | MAX  | UNITS | NOTES |
|---|--|------|------|------|-------|-------|
| <b>SUPPLY VOLTAGES</b>                                      |  |      |      |      |       |       |
| VDD   |  | 1.71 | 1.8  | 3.6  | V     | 1     |
| VDDIO   |  | 1.71 | 1.8  | 1.95 | V     | 1     |
| <b>SUPPLY CURRENTS</b>                                      |  |      |      |      |       |       |
| 9-Axis (DMP disabled)                                       | Low-Noise Mode; Compass in Continuous Mode                                   |      | 3.11 |      | mA    | 2     |
| Gyroscope Only (DMP, Barometer & Accelerometer disabled)    | Low-Power Mode, 102.3 Hz update rate, 1x averaging filter                    |      | 1.23 |      | mA    | 2     |
| Accelerometer Only (DMP, Barometer & Gyroscope disabled)    | Low-Power Mode, 102.3 Hz update rate, 1x averaging filter                    |      | 68.9 |      | μA    | 2     |
| Magnetometer Only (DMP, Accelerometer & Gyroscope disabled) | 8 Hz update rate   |      | 90   |      | μA    | 2     |
| Full-Chip Sleep Mode  |  |      | 8    |      | μA    | 2     |
| <b>TEMPERATURE RANGE</b>                                    |  |      |      |      |       |       |
| Specified Temperature Range                                 | Performance parameters are not applicable beyond Specified Temperature Range | -40  |      | +85  | °C    | 1     |

**Table 4. D.C. Electrical Characteristics**

**NOTES:**

1. Guaranteed by design.
2. Derived from validation or characterization of parts, not guaranteed in production.

## A.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

| PARAMETER  | CONDITIONS  | MIN                  | TYP        | MAX          | UNITS    | NOTES |
|--|---|----------------------|------------|--------------|----------|-------|
| SUPPLIES   |   |                      |            |              |          |       |
| Supply Ramp Time (T <sub>RAMP</sub> )  | Monotonic ramp. Ramp rate is 10% to 90% of the final value. | 0.01                 | 20         | 100          | ms       | 1     |
| TEMPERATURE SENSOR   |   |                      |            |              |          |       |
| Operating Range  | Ambient   | -40                  |            | 85           | °C       | 1     |
| Sensitivity  | Untrimmed   |                      | 333.87     |              | LSB/°C   |       |
| Room Temp Offset   | 21°C  |                      | 0          |              | LSB      |       |
| POWER-ON RESET   |   |                      |            |              |          |       |
| Supply Ramp Time (T <sub>RAMP</sub> )  | Valid power-on RESET  | 0.01                 | 20         | 100          | ms       | 1     |
| Start-up time for register read/write  | From power-up   |                      | 11         | 100          | ms       | 1     |
| I <sup>2</sup> C ADDRESS   | AD0 = 0   |                      | 1101000    |              |          |       |
|  | AD0 = 1   |                      | 1101001    |              |          |       |
| DIGITAL INPUTS (FSYNC, AD0, SCLK, SDI, CS)                                       |   |                      |            |              |          |       |
| V <sub>IH</sub> , High Level Input Voltage                                       |   | 0.7*VDDIO            |            |              | V        | 1     |
| V <sub>IL</sub> , Low Level Input Voltage  |   |                      |            | 0.3*VDDIO    | V        |       |
| C <sub>i</sub> , Input Capacitance   |   |                      | < 10       |              | pF       |       |
| DIGITAL OUTPUT (SDO, INT)  |   |                      |            |              |          |       |
| V <sub>OH</sub> , High Level Output Voltage                                      | R <sub>LOAD</sub> =1 MΩ;                                    | 0.9*VDDIO            |            |              | V        | 1     |
| V <sub>OL1</sub> , LOW-Level Output Voltage                                      | R <sub>LOAD</sub> =1 MΩ;                                    |                      |            | 0.1*VDDIO    | V        |       |
| V <sub>OL,INT1</sub> , INT Low-Level Output Voltage                              | OPEN=1, 0.3 mA sink Current                                 |                      |            | 0.1          | V        |       |
| Output Leakage Current   | OPEN=1  |                      | 100        |              | nA       |       |
| t <sub>INT</sub> , INT Pulse Width   | LATCH_INT_EN=0  |                      | 50         |              | μs       |       |
| I <sup>2</sup> C I/O (SCL, SDA)  |   |                      |            |              |          |       |
| V <sub>IL</sub> , LOW Level Input Voltage  |   | -0.5V                |            | 0.3*VDDIO    | V        | 1     |
| V <sub>IH</sub> , HIGH-Level Input Voltage                                       |   | 0.7*VDDIO            |            | VDDIO + 0.5V | V        |       |
| V <sub>hys</sub> , Hysteresis  |   |                      | 0.1*VDDIO  |              | V        |       |
| V <sub>OL</sub> , LOW-Level Output Voltage                                       | 3 mA sink current   | 0                    |            | 0.4          | V        |       |
| I <sub>OL</sub> , LOW-Level Output Current                                       | V <sub>OL</sub> =0.4V<br>V <sub>OL</sub> =0.6V              |                      | 3<br>6     |              | mA<br>mA |       |
| Output Leakage Current   |   |                      | 100        |              | nA       |       |
| t <sub>of</sub> , Output Fall Time from V <sub>IHmax</sub> to V <sub>ILmax</sub> | C <sub>b</sub> bus capacitance in pf                        | 20+0.1C <sub>b</sub> |            | 250          | ns       |       |
| AUXILLIARY I/O (AUX_CL, AUX_DA)  |   |                      |            |              |          |       |
| V <sub>IL</sub> , LOW-Level Input Voltage  |   | -0.5V                |            | 0.3*VDDIO    | V        | 1     |
| V <sub>IH</sub> , HIGH-Level Input Voltage                                       |   | 0.7* VDDIO           |            | VDDIO + 0.5V | V        |       |
| V <sub>hys</sub> , Hysteresis  |   |                      | 0.1* VDDIO |              | V        |       |
| V <sub>OL1</sub> , LOW-Level Output Voltage                                      | VDDIO > 2V; 1 mA sink current                               | 0                    |            | 0.4          | V        |       |
| V <sub>OL3</sub> , LOW-Level Output Voltage                                      | VDDIO < 2V; 1 mA sink current                               | 0                    |            | 0.2* VDDIO   | V        |       |
| I <sub>OL</sub> , LOW-Level Output Current                                       | V <sub>OL</sub> = 0.4V<br>V <sub>OL</sub> = 0.6V            |                      | 3<br>6     |              | mA<br>mA |       |
| Output Leakage Current   |   |                      | 100        |              | nA       |       |
| t <sub>of</sub> , Output Fall Time from V <sub>IHmax</sub> to V <sub>ILmax</sub> | C <sub>b</sub> bus capacitance in pF                        | 20+0.1C <sub>b</sub> |            | 250          | ns       |       |

| PARAMETER                            | CONDITIONS   | MIN | TYP | MAX | UNITS | NOTES |
|--------------------------------------|--|-----|-----|-----|-------|-------|
| <b>INTERNAL CLOCK SOURCE</b>         |  |     |     |     |       |       |
| Clock Frequency Initial Tolerance    | Accelerometer Only Mode                              | -5  |     | +5  | %     | 1     |
|                                      | Gyroscope or 6-Axis Mode WITHOUT Timebase Correction | -9  |     | +9  | %     | 1     |
|                                      | Gyroscope or 6-Axis Mode WITH Timebase Correction    | -1  |     | +1  |       |       |
| Frequency Variation over Temperature | Accelerometer Only Mode                              | -10 |     | +10 | %     | 1     |
|                                      | Gyroscope or 6-Axis Mode                             |     | ±1  |     | %     | 1     |

**Table 5. A.C. Electrical Characteristics**

**NOTES:**

1. Derived from validation or characterization of parts, not guaranteed in production.

## Other Electrical Specifications

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

| PARAMETER   | CONDITIONS                   | MIN | TYP      | MAX | UNITS | NOTES |
|---|------------------------------|-----|----------|-----|-------|-------|
| <b>SERIAL INTERFACE</b>                           |                              |     |          |     |       |       |
| SPI Operating Frequency, All Registers Read/Write | Low Speed Characterization   |     | 100 ±10% |     | kHz   |       |
|   | High Speed Characterization  |     | 7 ±10%   |     | MHz   |       |
| I <sup>2</sup> C Operating Frequency              | All registers, Fast-mode     |     |          | 400 | kHz   |       |
|   | All registers, Standard-mode |     |          | 100 | kHz   |       |

**Table 6. Other Electrical Specifications**

**NOTES:**

1. Derived from validation or characterization of parts, not guaranteed in production.

### 3.5 I<sup>2</sup>C TIMING CHARACTERIZATION

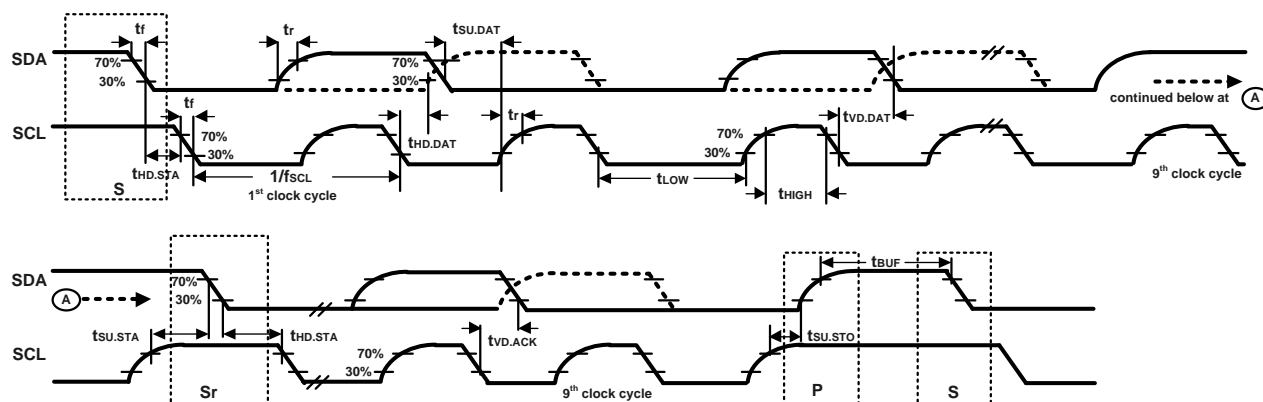
Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

| PARAMETERS  | CONDITIONS                                | MIN                        | TYPICAL | MAX | UNITS | NOTES |
|---|---|----------------------------|---------|-----|-------|-------|
| I <sup>2</sup> C TIMING   |   | I <sup>2</sup> C FAST-MODE |         |     |       |       |
| f <sub>SCL</sub> , SCL Clock Frequency                            |   |                            |         | 400 | kHz   | 1, 2  |
| t <sub>HD.STA</sub> , (Repeated) START Condition Hold Time        |   | 0.6                        |         |     | μs    | 1, 2  |
| t <sub>LOW</sub> , SCL Low Period                                 |   | 1.3                        |         |     | μs    | 1, 2  |
| t <sub>HIGH</sub> , SCL High Period                               |   | 0.6                        |         |     | μs    | 1, 2  |
| t <sub>SU.STA</sub> , Repeated START Condition Setup Time         |   | 0.6                        |         |     | μs    | 1, 2  |
| t <sub>HD.DAT</sub> , SDA Data Hold Time                          |   | 0                          |         |     | μs    | 1, 2  |
| t <sub>SU.DAT</sub> , SDA Data Setup Time                         |   | 100                        |         |     | ns    | 1, 2  |
| t <sub>r</sub> , SDA and SCL Rise Time                            | C <sub>b</sub> bus cap. from 10 to 400 pF | 20+0.1C <sub>b</sub>       |         | 300 | ns    | 1, 2  |
| t <sub>f</sub> , SDA and SCL Fall Time                            | C <sub>b</sub> bus cap. from 10 to 400 pF | 20+0.1C <sub>b</sub>       |         | 300 | ns    | 1, 2  |
| t <sub>SU.STO</sub> , STOP Condition Setup Time                   |   | 0.6                        |         |     | μs    | 1, 2  |
| t <sub>BUF</sub> , Bus Free Time Between STOP and START Condition |   | 1.3                        |         |     | μs    | 1, 2  |
| C <sub>b</sub> , Capacitive Load for each Bus Line                |   |                            | < 400   |     | pF    | 1, 2  |
| t <sub>VD.DAT</sub> , Data Valid Time                             |   |                            |         | 0.9 | μs    | 1, 2  |
| t <sub>VD.ACK</sub> , Data Valid Acknowledge Time                 |   |                            |         | 0.9 | μs    | 1, 2  |

**Table 7. I<sup>2</sup>C Timing Characteristics**

**NOTES:**

1. Timing Characteristics apply to both Primary and Auxiliary I<sup>2</sup>C Bus.
2. Based on characterization of 5 parts over temperature and voltage as mounted on evaluation board or in sockets.



**Figure 1. I<sup>2</sup>C Bus Timing Diagram**



### 3.6 SPI TIMING CHARACTERIZATION

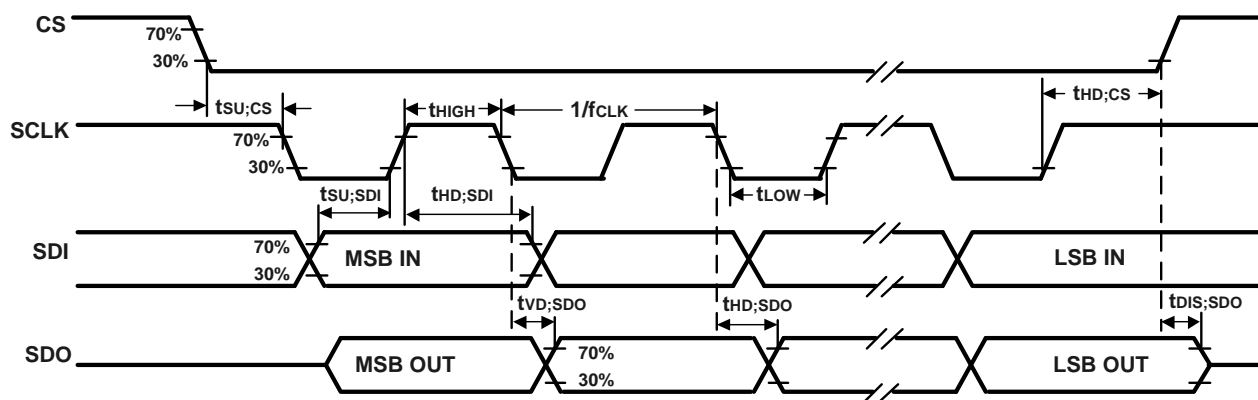
Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T<sub>A</sub>=25°C, unless otherwise noted.

| PARAMETERS                                     | CONDITIONS                | MIN | TYPICAL | MAX | UNITS | NOTES |
|--|---------------------------|-----|---------|-----|-------|-------|
| <b>SPI TIMING</b>                              |                           |     |         |     |       |       |
| f <sub>SCLK</sub> , SCLK Clock Frequency       |                           |     |         | 7   | MHz   |       |
| t <sub>LOW</sub> , SCLK Low Period             |                           | 64  |         |     | ns    |       |
| t <sub>HIGH</sub> , SCLK High Period           |                           | 64  |         |     | ns    |       |
| t <sub>SU,CS</sub> , CS Setup Time             |                           | 8   |         |     | ns    |       |
| t <sub>HD,CS</sub> , CS Hold Time              |                           | 500 |         |     | ns    |       |
| t <sub>SU,SDI</sub> , SDI Setup Time           |                           | 5   |         |     | ns    |       |
| t <sub>HD,SDI</sub> , SDI Hold Time            |                           | 7   |         |     | ns    |       |
| t <sub>VD,SDO</sub> , SDO Valid Time           | C <sub>load</sub> = 20 pF |     |         | 59  | ns    |       |
| t <sub>HD,SDO</sub> , SDO Hold Time            | C <sub>load</sub> = 20 pF | 6   |         |     | ns    |       |
| t <sub>DIS,SDO</sub> , SDO Output Disable Time |                           |     |         | 50  | ns    |       |

**Table 8. SPI Timing Characteristics (7 MHz)**

**NOTES:**

- Based on characterization of 5 parts over temperature and voltage as mounted on evaluation board or in sockets



**Figure 2. SPI Bus Timing Diagram**

## 3.7 ABSOLUTE MAXIMUM RATINGS

Stress above those listed as “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these conditions is not implied. Exposure to the absolute maximum ratings conditions for extended periods may affect device reliability.

| PARAMETER   | RATING                               |
|---|--------------------------------------|
| Supply Voltage, VDD                                     | -0.5V to +4V                         |
| Supply Voltage, VDDIO                                   | -0.3V to +2.5V                       |
| REGOUT  | -0.5V to 2V                          |
| Input Voltage Level (AUX_DA, AD0, FSYNC, INT, SCL, SDA) | -0.5V to VDD + 0.5V                  |
| Acceleration (Any Axis, unpowered)                      | 20,000g for 0.2 ms                   |
| Operating Temperature Range                             | -40°C to +105°C                      |
| Storage Temperature Range                               | -40°C to +125°C                      |
| Electrostatic Discharge (ESD) Protection                | 2kV (HBM);<br>200V (MM)              |
| Latch-up  | JEDEC Class II (2), 125°C<br>±100 mA |

**Table 9. Absolute Maximum Ratings**

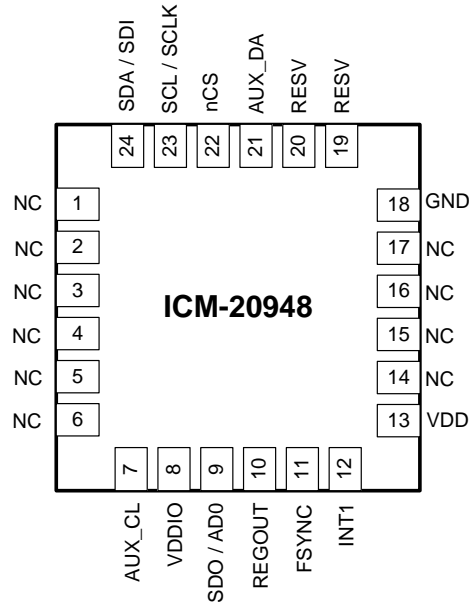
## 4 APPLICATIONS INFORMATION

### 4.1 PIN OUT DIAGRAM AND SIGNAL DESCRIPTION

| PIN NUMBER     | PIN NAME   | PIN DESCRIPTION  |
|----------------|------------|--|
| 7              | AUX_CL     | I <sup>2</sup> C Master serial clock, for connecting to external sensors |
| 8              | VDDIO      | Digital I/O supply voltage   |
| 9              | AD0 / SDO  | I <sup>2</sup> C Slave Address LSB (AD0); SPI serial data output (SDO)   |
| 10             | REGOUT     | Regulator filter capacitor connection                                    |
| 11             | FSYNC      | Frame synchronization digital input. Connect to GND if unused            |
| 12             | INT1       | Interrupt 1  |
| 13             | VDD        | Power supply voltage   |
| 18             | GND        | Power supply ground  |
| 19             | RESV       | Reserved. Do not connect.  |
| 20             | RESV       | Reserved. Connect to GND.  |
| 21             | AUX_DA     | I <sup>2</sup> C master serial data, for connecting to external sensors  |
| 22             | nCS        | Chip select (SPI mode only)  |
| 23             | SCL / SCLK | I <sup>2</sup> C serial clock (SCL); SPI serial clock (SCLK)             |
| 24             | SDA / SDI  | I <sup>2</sup> C serial data (SDA); SPI serial data input (SDI)          |
| 1 – 6, 14 – 17 | NC         | Do not connect   |

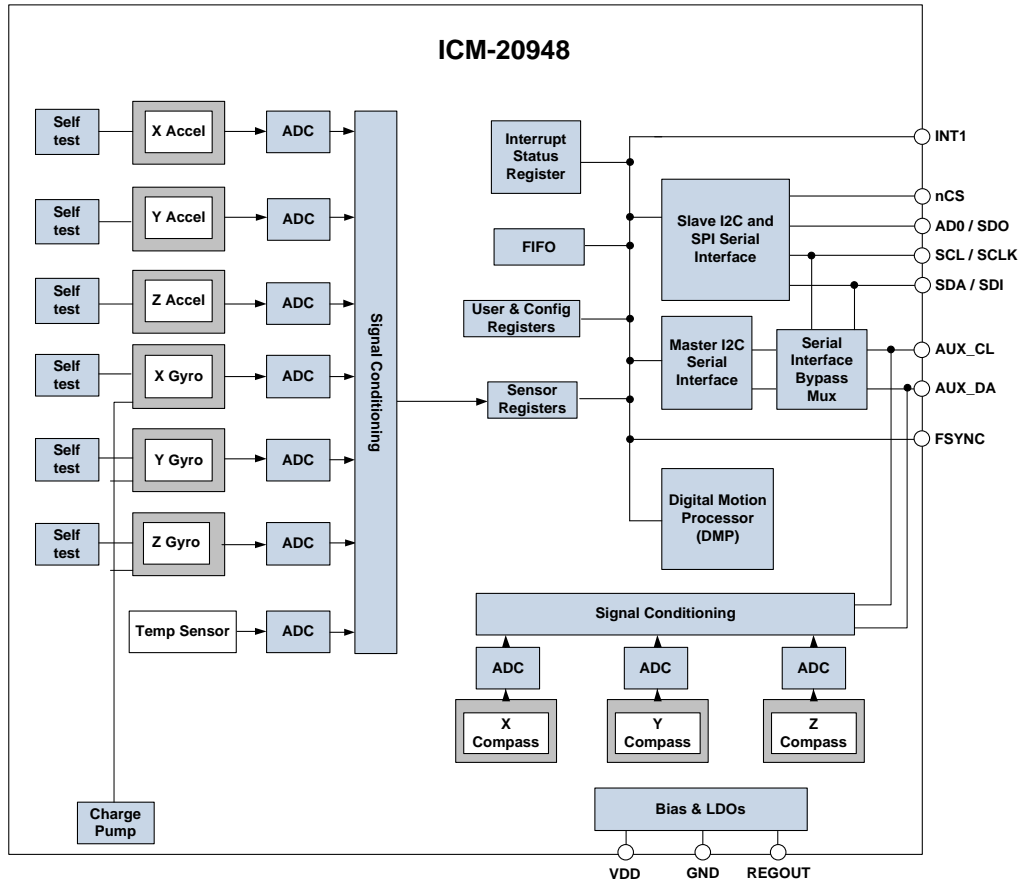
**Table 10. Signal Descriptions**

**NOTE:** Power up with SCL/SCLK and nCS pins held low is not a supported use case. In case this power up approach is used, software reset is required using the PWR\_MGMT\_1 register, prior to initialization.



**Figure 3. Pin out Diagram for ICM-20948 3 mm x 3 mm x 1 mm QFN**





#### **4.7 THREE-AXIS MEMS GYROSCOPE WITH 16-BIT ADCS AND SIGNAL CONDITIONING**

The ICM-20948 consists of three independent vibratory MEMS rate gyroscopes, which detect rotation about the X-, Y-, and Z-Axes. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a vibration that is detected by a capacitive pickoff. The resulting signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. This voltage is digitized using individual on-chip 16-bit Analog-to-Digital Converters (ADCs) to sample each axis. The full-scale range of the gyro sensors may be digitally programmed to  $\pm 250$ ,  $\pm 500$ ,  $\pm 1000$ , or  $\pm 2000$  degrees per second (dps).

#### **4.8 THREE-AXIS MEMS ACCELEROMETER WITH 16-BIT ADCS AND SIGNAL CONDITIONING**

The ICM-20948's 3-Axis accelerometer uses separate proof masses for each axis. Acceleration along a particular axis induces displacement on the corresponding proof mass, and capacitive sensors detect the displacement differentially. The ICM-20948's architecture reduces the accelerometers' susceptibility to fabrication variations as well as to thermal drift. When the device is placed on a flat surface, it will measure 0g on the X- and Y-axes and +1g on the Z-axis. The accelerometers' scale factor is calibrated at the factory and is nominally independent of supply voltage. Each sensor has a dedicated sigma-delta ADC for providing digital outputs. The full scale range of the digital output can be adjusted to  $\pm 2g$ ,  $\pm 4g$ ,  $\pm 8g$ , or  $\pm 16g$ .

#### **4.9 THREE-AXIS MEMS MAGNETOMETER WITH 16-BIT ADCS AND SIGNAL CONDITIONING**

The 3-axis magnetometer uses highly sensitive Hall sensor technology. The magnetometer portion of the IC incorporates magnetic sensors for detecting terrestrial magnetism in the X-, Y-, and Z-Axes, a sensor driving circuit, a signal amplifier chain, and an arithmetic circuit for processing the signal from each sensor. Each ADC has a 16-bit resolution and a full scale range of  $\pm 4900 \mu T$ .

#### **4.10 DIGITAL MOTION PROCESSOR**

The embedded Digital Motion Processor (DMP) within the ICM-20948 offloads computation of motion processing algorithms from the host processor. The DMP acquires data from accelerometers, gyroscopes, and additional third party sensors such as magnetometers, and processes the data. The resulting data can be read from the FIFO. The DMP has access to the external pins, which can be used for generating interrupts.

The purpose of the DMP is to offload both timing requirements and processing power from the host processor. Typically, motion processing algorithms should be run at a high rate, often around 200 Hz, in order to provide accurate results with low latency. This is required even if the application updates at a much lower rate; for example, a low power user interface may update as slowly as 5 Hz, but the motion processing should still run at 200 Hz. The DMP can be used to minimize power, simplify timing, simplify the software architecture, and save valuable MIPS on the host processor for use in applications.

#### **4.11 PRIMARY I<sup>2</sup>C AND SPI SERIAL COMMUNICATIONS INTERFACES**

The ICM-20948 communicates to a system processor using either a SPI or an I<sup>2</sup>C serial interface. The ICM-20948 always acts as a slave when communicating to the system processor. The LSB of the of the I<sup>2</sup>C slave address is set by pin 1 (AD0).

##### **ICM-20948 Solution Using I<sup>2</sup>C Interface**

In Figure 6, the system processor is an I<sup>2</sup>C master to the ICM-20948. In addition, the ICM-20948 is an I<sup>2</sup>C master to the optional external sensor. The ICM-20948 has limited capabilities as an I<sup>2</sup>C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors. The ICM-20948 has an interface bypass multiplexer, which connects the system processor I<sup>2</sup>C bus pins 23 and 24 (SCL and SDA) directly to the auxiliary sensor I<sup>2</sup>C bus pins 7 and 21 (AUX\_CL and AUX\_DA).

Once the auxiliary sensors have been configured by the system processor, the interface bypass multiplexer should be disabled so that the ICM-20948 auxiliary I<sup>2</sup>C master can take control of the sensor I<sup>2</sup>C bus and gather data from the auxiliary sensors.

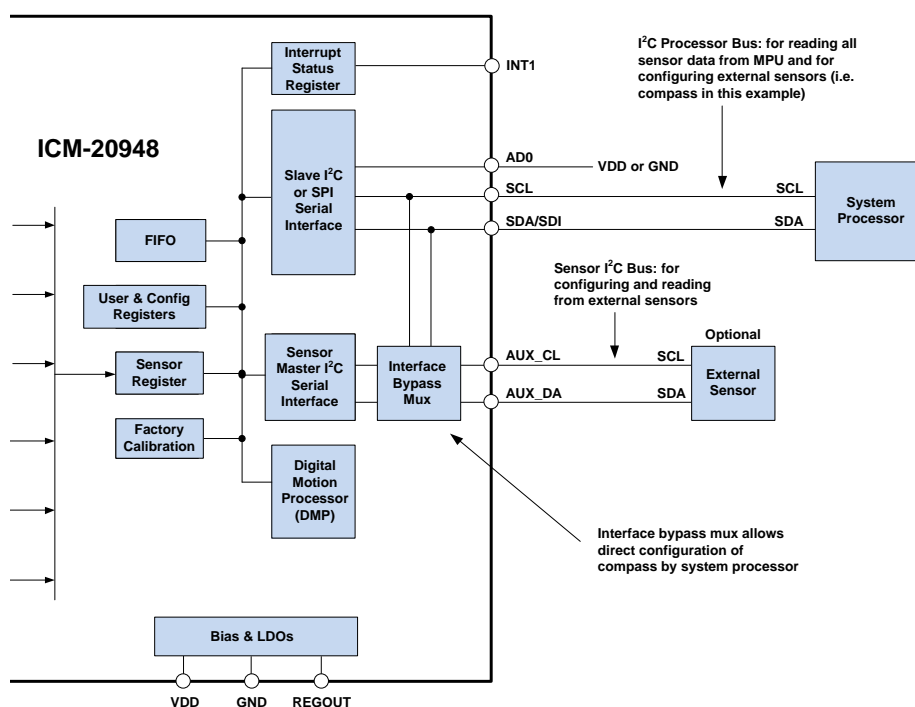


Figure 6. ICM-20948 Solution Using I<sup>2</sup>C Interface

## ICM-20948 Solution Using SPI Interface

In Figure 7, the system processor is an SPI master to the ICM-20948. Pins 9, 22, 23, and 24 are used to support the SDO, nCS, SCLK, and SDI signals for SPI communications. Because these SPI pins are shared with the I<sup>2</sup>C slave pins (9, 23 and 24), the system processor cannot access the auxiliary I<sup>2</sup>C bus through the interface bypass multiplexer, which connects the processor I<sup>2</sup>C interface pins to the sensor I<sup>2</sup>C interface pins. Since the ICM-20948 has limited capabilities as an I<sup>2</sup>C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors, another method must be used for programming the sensors on the auxiliary sensor I<sup>2</sup>C bus pins 7 and 21 (AUX\_CL and AUX\_DA).

When using SPI communications between the ICM-20948 and the system processor, configuration of devices on the auxiliary I<sup>2</sup>C sensor bus can be achieved by using I<sup>2</sup>C Slaves 0-4 to perform read and write transactions on any device and register on the auxiliary I<sup>2</sup>C bus. The I<sup>2</sup>C Slave 4 interface can be used to perform only single byte read and write transactions. Once the external sensors have been configured, the ICM-20948 can perform single or multi-byte reads using the sensor I<sup>2</sup>C bus. The read results from the Slave 0-3 controllers can be written to the FIFO buffer as well as to the external sensor registers.

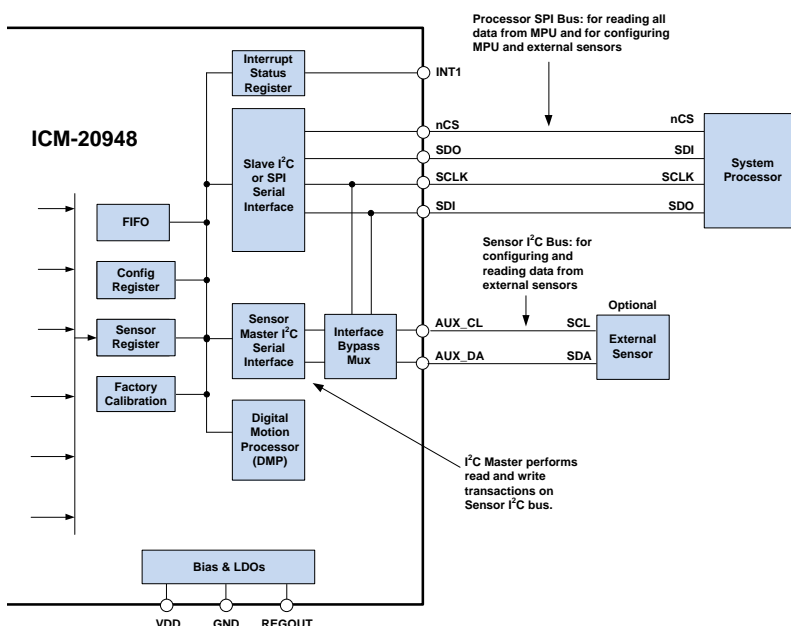


Figure 7. ICM-20948 Solution Using SPI Interface

## 4.12 AUXILIARY I²C SERIAL INTERFACE

The ICM-20948 has an auxiliary I²C bus for communicating to external sensors. This bus has two operating modes:

- **I²C Master Mode:** The ICM-20948 acts as a master to any external sensors connected to the auxiliary I²C bus
- **Pass-Through Mode:** The ICM-20948 directly connects the primary and auxiliary I²C buses together, allowing the system processor to directly communicate with any external sensors.

### Auxiliary I²C Bus Modes of Operation:

- **I²C Master Mode:** Allows the ICM-20948 to directly access the data registers of external sensors. In this mode, the ICM-20948 directly obtains data from auxiliary sensors without intervention from the system applications processor. The I²C Master can be configured to read up to 24 bytes from up to 4 auxiliary sensors. A fifth sensor can be configured to work single byte read/write mode.
- **Pass-Through Mode:** Allows an external system processor to act as master and directly communicate to the external sensors connected to the auxiliary I²C bus pins (AUX\_DA and AUX\_CL). In this mode, the auxiliary I²C bus control logic of the ICM-20948 is disabled, and the auxiliary I²C pins AUX\_CL and AUX\_DA (pins 7 and 21) are connected to the main I²C bus (Pins 23 and 24) through analog switches internally. Pass-Through mode is useful for configuring the external sensors.

## 4.13 SELF-TEST

Self-test allows for the testing of the mechanical and electrical portions of the sensors. The self-test for each measurement axis can be activated by means of the gyroscope and accelerometer self-test registers.

When the self-test is activated, the electronics cause the sensors to be actuated and produce an output signal. The output signal is used to observe the self-test response.

The self-test response is defined as follows:

$$\text{SELF-TEST RESPONSE} = \text{SENSOR OUTPUT WITH SELF-TEST ENABLED} - \text{SENSOR OUTPUT WITHOUT SELF-TEST ENABLED}$$



The self-test response for each gyroscope axis is defined in the gyroscope specification table, while that for each accelerometer axis is defined in the accelerometer specification table.

When the value of the self-test response is within the specified min/max limits, the part has passed self-test. When the self-test response exceeds the min/max values, the part is deemed to have failed self-test. It is recommended to use InvenSense MotionApps software for executing self-test.

#### **4.14 CLOCKING**

The internal system clock sources include: (1) an internal relaxation oscillator, and (2) a PLL with MEMS gyroscope oscillator as the reference clock. With the recommended clock selection setting (CLKSEL = 1), the best clock source for optimum sensor performance and power consumption will be automatically selected based on the power mode. Specifically, the internal relaxation oscillator will be selected when operating in accelerometer only mode, while the PLL will be selected whenever gyroscope is on, which includes gyroscope and 6-axis modes.

As clock accuracy is critical to the preciseness of distance and angle calculations performed by DMP, it should be noted that the internal relaxation oscillator and PLL show different performances in some aspects. The internal relaxation oscillator is trimmed to have a consistent operating frequency at room temperature, while the PLL clock frequency varies from part to part. The PLL frequency deviation from the nominal value in percentage is captured in register TIMEBASE\_CORRECTION\_PLL (detailed in section 12.5), and users can factor it in during distance and angle calculations to not sacrifice accuracy. Other than that, PLL has better frequency stability and lower frequency variation over temperature than the internal relaxation oscillator.

#### **4.15 SENSOR DATA REGISTERS**

The sensor data registers contain the latest gyro, accelerometer, auxiliary sensor, and temperature measurement data. They are read-only registers, and are accessed via the serial interface. Data from these registers may be read anytime.

#### **4.16 FIFO**

The ICM-20948 contains a FIFO of size 512 bytes (FIFO size will vary depending on DMP feature-set) that is accessible via the Serial Interface. The FIFO configuration register determines which data is written into the FIFO. Possible choices include gyro data, accelerometer data, temperature readings, auxiliary sensor readings, and FSYNC input.

A FIFO counter keeps track of how many bytes of valid data are contained in the FIFO. The FIFO register supports burst reads. The interrupt function may be used to determine when new data is available.

For further information regarding the FIFO, please refer to the Section 7.

#### **4.17 FSYNC**

The FSYNC pin can be used from an external interrupt source to wake up the device from sleep. It is particularly useful in EIS applications to synchronize the gyroscope ODR with external inputs from an imaging sensor. Connecting the VSYNC or HSYNC pin of the image sensor subsystem to FSYNC on ICM-20948 allows timing synchronization between the two otherwise unconnected subsystems.

An FSYNC\_ODR delay time register is used to capture the delay between an FSYNC pulse and the very next gyroscope data ready pulse.

#### **4.18 INTERRUPTS**

Interrupt functionality is configured via the Interrupt Configuration register. Items that are configurable include the INT pin configuration, the interrupt latching and clearing method, and triggers for the interrupt. Section 5 provides a summary of interrupt sources. The interrupt status can be read from the Interrupt Status register.

For further information regarding interrupts, please refer to Section 7.

## 4.19 DIGITAL-OUTPUT TEMPERATURE SENSOR

An on-chip temperature sensor and ADC are used to measure the ICM-20948 die temperature. The readings from the ADC can be read from the FIFO or the Sensor Data registers.

## 4.20 BIAS AND LDOS

The bias and LDO section generates the internal supply and the reference voltages and currents required by the ICM-20948. Its two inputs are an unregulated VDD and a VDDIO logic reference supply voltage. The LDO output is bypassed by a capacitor at REGOUT. For further details on the capacitor, please refer to the Bill of Materials for External Components.

## 4.21 CHARGE PUMP

An on-chip charge pump generates the high voltage required for the MEMS oscillators.

## 4.22 POWER MODES

Table 12 lists the user-accessible power modes for ICM-20948.

| MODE | NAME                         | GYRO | ACCEL       | MAGNETOMETER | DMP       |
|------|------------------------------|------|-------------|--------------|-----------|
| 1    | Sleep Mode                   | Off  | Off         | Off          | Off       |
| 2    | Low-Power Accelerometer Mode | Off  | Duty-Cycled | Off          | On or Off |
| 3    | Low-Noise Accelerometer Mode | Off  | On          | Off          | On or Off |
| 4    | Gyroscope Mode               | On   | Off         | Off          | On or Off |
| 5    | Magnetometer Mode            | Off  | Off         | On           | On or Off |
| 6    | Accel + Gyro Mode            | On   | On          | Off          | On or Off |
| 7    | Accel + Magnetometer Mode    | Off  | On          | On           | On or Off |
| 8    | 9-Axis Mode                  | On   | On          | On           | On or Off |

**Table 12. Power Modes for ICM-20948**

## **5 PROGRAMMABLE INTERRUPTS**

The ICM-20948 has a programmable interrupt system which can generate an interrupt signal on the INT pin. Status flags indicate the source of an interrupt. Interrupt sources may be enabled and disabled individually. Table 13 lists the interrupt sources.

| INTERRUPT SOURCE         |
|--------------------------|
| DMP Interrupt            |
| Wake on Motion Interrupt |
| PLL RDY Interrupt        |
| I2C Master Interrupt     |
| Raw Data Ready Interrupt |
| FIFO Overflow Interrupt  |
| FIFO Watermark Interrupt |

**Table 13. Interrupt Sources**

## 6 DIGITAL INTERFACE

### 6.1 I<sup>2</sup>C AND SPI SERIAL INTERFACES

The internal registers and memory of the ICM-20948 can be accessed using either I<sup>2</sup>C at 400 kHz or SPI at 7 MHz. SPI operates in four-wire mode.

| PIN NUMBER | PIN NAME   | PIN DESCRIPTION  |
|------------|------------|--|
| 9          | AD0 / SDO  | I <sup>2</sup> C Slave Address LSB (AD0); SPI serial data output (SDO) |
| 22         | nCS        | Chip select (SPI mode only)  |
| 23         | SCL / SCLK | I <sup>2</sup> C serial clock (SCL); SPI serial clock (SCLK)           |
| 24         | SDA / SDI  | I <sup>2</sup> C serial data (SDA); SPI serial data input (SDI)        |

**Table 14. Serial Interface**

**NOTE:** To prevent switching into I<sup>2</sup>C mode when using SPI, the I<sup>2</sup>C interface should be disabled by setting the **I2C\_IF\_DIS** configuration bit. Setting this bit should be performed immediately after waiting for the time specified by the “Start-Up Time for Register Read/Write” in Section 6.3.

For further information regarding the *I2C\_IF\_DIS* bit, please refer to Section 7.

### 6.2 I<sup>2</sup>C INTERFACE

I<sup>2</sup>C is a two-wire interface comprised of the signals serial data (SDA) and serial clock (SCL). In general, the lines are open-drain and bi-directional. In a generalized I<sup>2</sup>C interface implementation, attached devices can be a master or a slave. The master device puts the slave address on the bus, and the slave device with the matching address acknowledges the master.

The ICM-20948 always operates as a slave device when communicating to the system processor, which thus acts as the master. SDA and SCL lines typically need pull-up resistors to VDD. The maximum bus speed is 400 kHz.

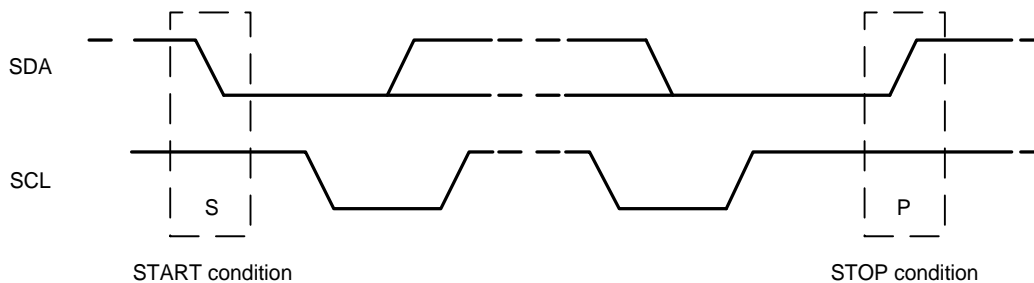
The slave address of the ICM-20948 is b110100X which is 7 bits long. The LSB bit of the 7-bit address is determined by the logic level on pin AD0. This allows two ICM-20948s to be connected to the same I<sup>2</sup>C bus. When used in this configuration, the address of the one of the devices should be b1101000 (pin AD0 is logic low) and the address of the other should be b1101001 (pin AD0 is logic high).

### 6.3 I<sup>2</sup>C COMMUNICATIONS PROTOCOL

#### START (S) and STOP (P) Conditions

Communication on the I<sup>2</sup>C bus starts when the master puts the START condition (S) on the bus, which is defined as a HIGH-to-LOW transition of the SDA line while SCL line is HIGH (see figure below). The bus is considered to be busy until the master puts a STOP condition (P) on the bus, which is defined as a LOW to HIGH transition on the SDA line while SCL is HIGH (see figure below).

Additionally, the bus remains busy if a repeated START (Sr) is generated instead of a STOP condition.

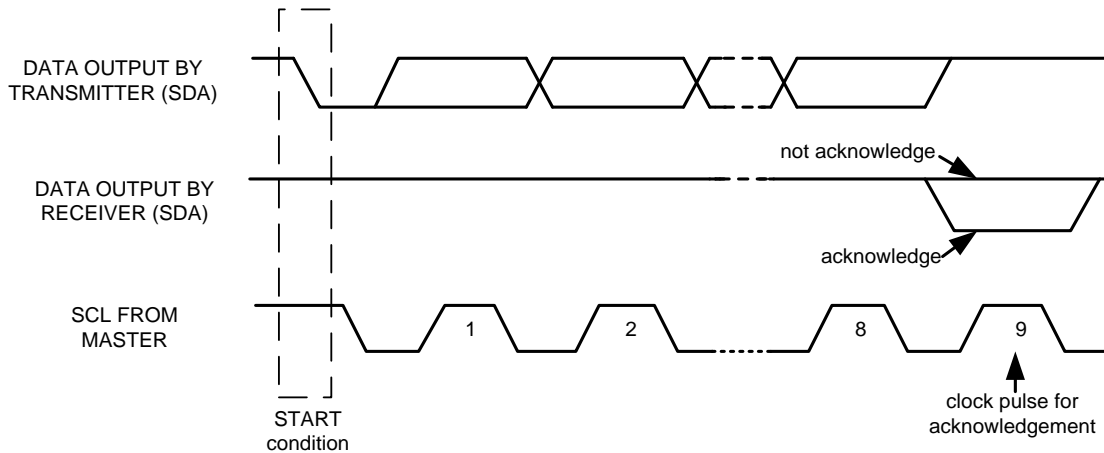


**Figure 8. START and STOP Conditions**

### Data Format / Acknowledge

I<sup>2</sup>C data bytes are defined to be 8-bits long. There is no restriction to the number of bytes transmitted per data transfer. Each byte transferred must be followed by an acknowledge (ACK) signal. The clock for the acknowledge signal is generated by the master, while the receiver generates the actual acknowledge signal by pulling down SDA and holding it low during the HIGH portion of the acknowledge clock pulse.

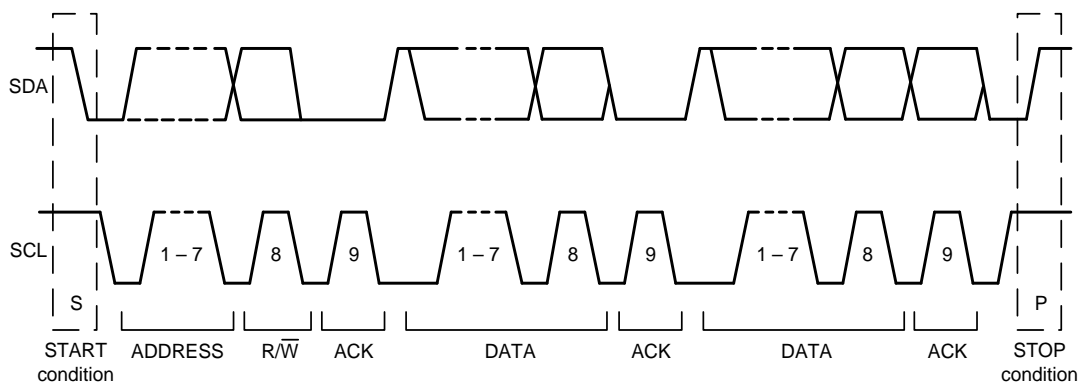
If a slave is busy and cannot transmit or receive another byte of data until some other task has been performed, it can hold SCL LOW, thus forcing the master into a wait state. Normal data transfer resumes when the slave is ready, and releases the clock line (refer to the following figure).



**Figure 9. Acknowledge on the I<sup>2</sup>C Bus**

### Communications

After beginning communications with the START condition (S), the master sends a 7-bit slave address followed by an 8<sup>th</sup> bit, the read/write bit. The read/write bit indicates whether the master is receiving data from or is writing to the slave device. Then, the master releases the SDA line and waits for the acknowledge signal (ACK) from the slave device. Each byte transferred must be followed by an acknowledge bit. To acknowledge, the slave device pulls the SDA line LOW and keeps it LOW for the high period of the SCL line. Data transmission is always terminated by the master with a STOP condition (P), thus freeing the communications line. However, the master can generate a repeated START condition (Sr), and address another slave without first generating a STOP condition (P). A LOW to HIGH transition on the SDA line while SCL is HIGH defines the stop condition. All SDA changes should take place when SCL is low, with the exception of start and stop conditions.



**Figure 10. Complete I<sup>2</sup>C Data Transfer**

To write the internal ICM-20948 registers, the master transmits the start condition (S), followed by the I<sup>2</sup>C address and the write bit (0). At the 9<sup>th</sup> clock cycle (when the clock is high), the ICM-20948 acknowledges the transfer. Then the master puts the register address (RA) on the bus. After the ICM-20948 acknowledges the reception of the register address, the master puts the register data onto the bus. This is followed by the ACK signal, and data transfer may be concluded by the stop condition (P). To write multiple bytes after the last ACK signal, the master can continue outputting data rather than transmitting a stop signal. In this case, the ICM-20948 automatically increments the register address and loads the data to the appropriate register. The following figures show single and two-byte write sequences.

### Single-Byte Write Sequence

|        |   |      |     |    |     |      |     |   |
|--------|---|------|-----|----|-----|------|-----|---|
| Master | S | AD+W |     | RA |     | DATA |     | P |
| Slave  |   |      | ACK |    | ACK |      | ACK |   |

### Burst Write Sequence

|        |   |      |     |    |     |      |     |      |     |   |
|--------|---|------|-----|----|-----|------|-----|------|-----|---|
| Master | S | AD+W |     | RA |     | DATA |     | DATA |     | P |
| Slave  |   |      | ACK |    | ACK |      | ACK |      | ACK |   |

To read the internal ICM-20948 registers, the master sends a start condition, followed by the I<sup>2</sup>C address and a write bit, and then the register address that is going to be read. Upon receiving the ACK signal from the ICM-20948, the master transmits a start signal followed by the slave address and read bit. As a result, the ICM-20948 sends an ACK signal and the data. The communication ends with a not acknowledge (NACK) signal and a stop bit from master. The NACK condition is defined such that the SDA line remains high at the 9<sup>th</sup> clock cycle. The following figures show single and two-byte read sequences.

### Single-Byte Read Sequence

|        |   |      |     |    |     |   |      |     |      |      |   |
|--------|---|------|-----|----|-----|---|------|-----|------|------|---|
| Master | S | AD+W |     | RA |     | S | AD+R |     |      | NACK | P |
| Slave  |   |      | ACK |    | ACK |   |      | ACK | DATA |      |   |

### Burst Read Sequence

|        |   |      |     |    |     |   |      |     |      |     |      |      |   |
|--------|---|------|-----|----|-----|---|------|-----|------|-----|------|------|---|
| Master | S | AD+W |     | RA |     | S | AD+R |     |      | ACK |      | NACK | P |
| Slave  |   |      | ACK |    | ACK |   |      | ACK | DATA |     | DATA |      |   |

## 6.4 I<sup>2</sup>C TERMS

| SIGNAL | DESCRIPTION  |
|--------|--|
| S      | Start Condition: SDA goes from high to low while SCL is high                               |
| AD     | Slave I <sup>2</sup> C address   |
| W      | Write bit (0)  |
| R      | Read bit (1)   |
| ACK    | Acknowledge: SDA line is low while the SCL line is high at the 9 <sup>th</sup> clock cycle |
| NACK   | Not-Acknowledge: SDA line stays high at the 9 <sup>th</sup> clock cycle                    |
| RA     | ICM-20948 internal register address  |
| DATA   | Transmit or received data  |
| P      | Stop condition: SDA going from low to high while SCL is high                               |

**Table 15. I<sup>2</sup>C Terms**

## 6.5 SPI INTERFACE

SPI is a 4-wire synchronous serial interface that uses two control lines and two data lines. The ICM-20948 always operates as a Slave device during standard Master-Slave SPI operation.

With respect to the Master, the Serial Clock output (SCLK), the Serial Data Output (SDO) and the Serial Data Input (SDI) are shared among the Slave devices. Each SPI slave device requires its own Chip Select (CS) line from the master.

CS goes low (active) at the start of transmission and goes back high (inactive) at the end. Only one CS line is active at a time, ensuring that only one slave is selected at any given time. The CS lines of the non-selected slave devices are held high, causing their SDO lines to remain in a high-impedance (high-z) state so that they do not interfere with any active devices.

### SPI Operational Features

1. Data is delivered MSB first and LSB last
2. Data is latched on the rising edge of SCLK
3. Data should be transitioned on the falling edge of SCLK
4. The maximum frequency of SCLK is 7MHz
5. SPI read and write operations are completed in 16 or more clock cycles (two or more bytes). The first byte contains the SPI Address, and the following byte(s) contain(s) the SPI data. The first bit of the first byte contains the Read/Write bit and indicates the Read (1) or Write (0) operation. The following 7 bits contain the Register Address. In cases of multiple-byte Read/Writes, data is two or more bytes:

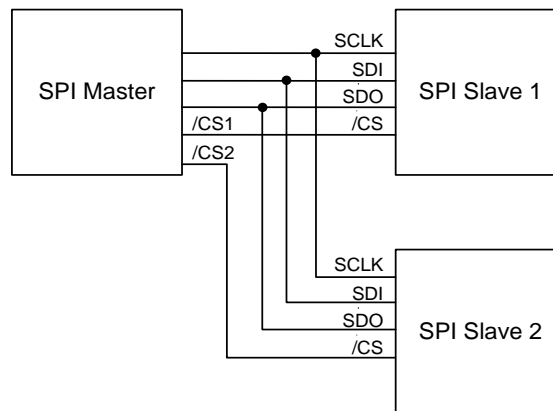
#### SPI Address format

| MSB |    |    |    |    |    |    | LSB |
|-----|----|----|----|----|----|----|-----|
| R/W | A6 | A5 | A4 | A3 | A2 | A1 | A0  |

#### SPI Data format

| MSB |    |    |    |    |    |    | LSB |
|-----|----|----|----|----|----|----|-----|
| D7  | D6 | D5 | D4 | D3 | D2 | D1 | D0  |

6. Supports Single or Burst Read/Writes.



**Figure 11. Typical SPI Master / Slave Configuration**

## 7 REGISTER MAP FOR GYROSCOPE AND ACCELEROMETER

The following table lists the register map for the ICM-20948, for user banks 0, 1, 2, 3.

### 7.1 USER BANK 0 REGISTER MAP

| ADDR<br>(HEX) | ADDR<br>(DEC.) | REGISTER NAME        | SERIAL<br>I/F | BIT7                      | BIT6          | BIT5              | BIT4                   | BIT3          | BIT2              | BIT1          | BIT0               |
|---------------|----------------|----------------------|---------------|---------------------------|---------------|-------------------|------------------------|---------------|-------------------|---------------|--------------------|
| 00            | 0              | WHO_AM_I             | R             | WHO_AM_I[7:0]             |               |                   |                        |               |                   |               |                    |
| 03            | 3              | USER_CTRL            | R/W           | DMP_EN                    | FIFO_EN       | I2C_MST_EN        | I2C_IF_DIS             | DMP_RST       | SRAM_RST          | I2C_MST_RST   | -                  |
| 05            | 5              | LP_CONFIG            | R/W           |                           | I2C_MST_CYCLE | ACCEL_CYCLE       | GYRO_CYCLE             | -             |                   |               |                    |
| 06            | 6              | PWR_MGMT_1           | R/W           | DEVICE_RESET              | SLEEP         | LP_EN             | -                      | TEMP_DIS      | CLKSEL[2:0]       |               |                    |
| 07            | 7              | PWR_MGMT_2           | R/W           | -                         |               | DISABLE_ACCEL     |                        |               | DISABLE_GYRO      |               |                    |
| 0F            | 15             | INT_PIN_CFG          | R/W           | INT1_ACTL                 | INT1_OPEN     | INT1_LATCH_INT_EN | INT_ANYRD_2CLEAR       | ACTL_FSYNC    | FSYNC_INT_MODE_EN | BYPASS_EN     | -                  |
| 10            | 16             | INT_ENABLE           | R/W           | REG_WOF_EN                | -             |                   |                        | WOM_INT_EN    | PLL_RDY_EN        | DMP_INT1_EN   | I2C_MST_INT_EN     |
| 11            | 17             | INT_ENABLE_1         | R/W           | -                         |               |                   |                        |               |                   |               | RAW_DATA_O_RDY_EN  |
| 12            | 18             | INT_ENABLE_2         | R/W           | -                         |               |                   | FIFO_OVERFLOW_EN[4:0]  |               |                   |               |                    |
| 13            | 19             | INT_ENABLE_3         | R/W           | -                         |               |                   | FIFO_WM_EN[4:0]        |               |                   |               |                    |
| 17            | 23             | I2C_MST_STATUS       | R/C           | PASS_THROUGH              | I2C_SLV4_DONE | I2C_LOST_ARB      | I2C_SLV4_NACK          | I2C_SLV3_NACK | I2C_SLV2_NACK     | I2C_SLV1_NACK | I2C_SLV0_NACK      |
| 19            | 25             | INT_STATUS           | R/C           | -                         |               |                   |                        | WOM_INT       | PLL_RDY_INT       | DMP_INT1      | I2C_MST_INT        |
| 1A            | 26             | INT_STATUS_1         | R/C           | -                         |               |                   |                        |               |                   |               | RAW_DATA_O_RDY_INT |
| 1B            | 27             | INT_STATUS_2         | R/C           | -                         |               |                   | FIFO_OVERFLOW_INT[4:0] |               |                   |               |                    |
| 1C            | 28             | INT_STATUS_3         | R/C           | -                         |               |                   | FIFO_WM_INT[4:0]       |               |                   |               |                    |
| 28            | 40             | DELAY_TIMEH          | R             | DELAY_TIMEH[7:0]          |               |                   |                        |               |                   |               |                    |
| 29            | 41             | DELAY_TIMEL          | R             | DELAY_TIMEL[7:0]          |               |                   |                        |               |                   |               |                    |
| 2D            | 45             | ACCEL_XOUT_H         | R             | ACCEL_XOUT_H[7:0]         |               |                   |                        |               |                   |               |                    |
| 2E            | 46             | ACCEL_XOUT_L         | R             | ACCEL_XOUT_L[7:0]         |               |                   |                        |               |                   |               |                    |
| 2F            | 47             | ACCEL_YOUT_H         | R             | ACCEL_YOUT_H[7:0]         |               |                   |                        |               |                   |               |                    |
| 30            | 48             | ACCEL_YOUT_L         | R             | ACCEL_YOUT_L[7:0]         |               |                   |                        |               |                   |               |                    |
| 31            | 49             | ACCEL_ZOUT_H         | R             | ACCEL_ZOUT_H[7:0]         |               |                   |                        |               |                   |               |                    |
| 32            | 50             | ACCEL_ZOUT_L         | R             | ACCEL_ZOUT_L[7:0]         |               |                   |                        |               |                   |               |                    |
| 33            | 51             | GYRO_XOUT_H          | R             | GYRO_XOUT_H[7:0]          |               |                   |                        |               |                   |               |                    |
| 34            | 52             | GYRO_XOUT_L          | R             | GYRO_XOUT_L[7:0]          |               |                   |                        |               |                   |               |                    |
| 35            | 53             | GYRO_YOUT_H          | R             | GYRO_YOUT_H[7:0]          |               |                   |                        |               |                   |               |                    |
| 36            | 54             | GYRO_YOUT_L          | R             | GYRO_YOUT_L[7:0]          |               |                   |                        |               |                   |               |                    |
| 37            | 55             | GYRO_ZOUT_H          | R             | GYRO_ZOUT_H[7:0]          |               |                   |                        |               |                   |               |                    |
| 38            | 56             | GYRO_ZOUT_L          | R             | GYRO_ZOUT_L[7:0]          |               |                   |                        |               |                   |               |                    |
| 39            | 57             | TEMP_OUT_H           | R             | TEMP_OUT_H[7:0]           |               |                   |                        |               |                   |               |                    |
| 3A            | 58             | TEMP_OUT_L           | R             | TEMP_OUT_L[7:0]           |               |                   |                        |               |                   |               |                    |
| 3B            | 59             | EXT_SLV_SENS_DATA_00 | R             | EXT_SLV_SENS_DATA_00[7:0] |               |                   |                        |               |                   |               |                    |
| 3C            | 60             | EXT_SLV_SENS_DATA_01 | R             | EXT_SLV_SENS_DATA_01[7:0] |               |                   |                        |               |                   |               |                    |
| 3D            | 61             | EXT_SLV_SENS_DATA_02 | R             | EXT_SLV_SENS_DATA_02[7:0] |               |                   |                        |               |                   |               |                    |
| 3E            | 62             | EXT_SLV_SENS_DATA_03 | R             | EXT_SLV_SENS_DATA_03[7:0] |               |                   |                        |               |                   |               |                    |
| 3F            | 63             | EXT_SLV_SENS_DATA_04 | R             | EXT_SLV_SENS_DATA_04[7:0] |               |                   |                        |               |                   |               |                    |
| 40            | 64             | EXT_SLV_SENS_DATA_05 | R             | EXT_SLV_SENS_DATA_05[7:0] |               |                   |                        |               |                   |               |                    |
| 41            | 65             | EXT_SLV_SENS_DATA_06 | R             | EXT_SLV_SENS_DATA_06[7:0] |               |                   |                        |               |                   |               |                    |
| 42            | 66             | EXT_SLV_SENS_DATA_07 | R             | EXT_SLV_SENS_DATA_07[7:0] |               |                   |                        |               |                   |               |                    |
| 43            | 67             | EXT_SLV_SENS_DATA_08 | R             | EXT_SLV_SENS_DATA_08[7:0] |               |                   |                        |               |                   |               |                    |



| ADDR<br>(HEX) | ADDR<br>(DEC.) | REGISTER NAME        | SERIAL<br>I/F | BIT7                      | BIT6 | BIT5           | BIT4            | BIT3              | BIT2           | BIT1           | BIT0          |  |
|---------------|----------------|----------------------|---------------|---------------------------|------|----------------|-----------------|-------------------|----------------|----------------|---------------|--|
| 44            | 68             | EXT_SLV_SENS_DATA_09 | R             | EXT_SLV_SENS_DATA_09[7:0] |      |                |                 |                   |                |                |               |  |
| 45            | 69             | EXT_SLV_SENS_DATA_10 | R             | EXT_SLV_SENS_DATA_10[7:0] |      |                |                 |                   |                |                |               |  |
| 46            | 70             | EXT_SLV_SENS_DATA_11 | R             | EXT_SLV_SENS_DATA_11[7:0] |      |                |                 |                   |                |                |               |  |
| 47            | 71             | EXT_SLV_SENS_DATA_12 | R             | EXT_SLV_SENS_DATA_12[7:0] |      |                |                 |                   |                |                |               |  |
| 48            | 72             | EXT_SLV_SENS_DATA_13 | R             | EXT_SLV_SENS_DATA_13[7:0] |      |                |                 |                   |                |                |               |  |
| 49            | 73             | EXT_SLV_SENS_DATA_14 | R             | EXT_SLV_SENS_DATA_14[7:0] |      |                |                 |                   |                |                |               |  |
| 4A            | 74             | EXT_SLV_SENS_DATA_15 | R             | EXT_SLV_SENS_DATA_15[7:0] |      |                |                 |                   |                |                |               |  |
| 4B            | 75             | EXT_SLV_SENS_DATA_16 | R             | EXT_SLV_SENS_DATA_16[7:0] |      |                |                 |                   |                |                |               |  |
| 4C            | 76             | EXT_SLV_SENS_DATA_17 | R             | EXT_SLV_SENS_DATA_17[7:0] |      |                |                 |                   |                |                |               |  |
| 4D            | 77             | EXT_SLV_SENS_DATA_18 | R             | EXT_SLV_SENS_DATA_18[7:0] |      |                |                 |                   |                |                |               |  |
| 4E            | 78             | EXT_SLV_SENS_DATA_19 | R             | EXT_SLV_SENS_DATA_19[7:0] |      |                |                 |                   |                |                |               |  |
| 4F            | 79             | EXT_SLV_SENS_DATA_20 | R             | EXT_SLV_SENS_DATA_20[7:0] |      |                |                 |                   |                |                |               |  |
| 50            | 80             | EXT_SLV_SENS_DATA_21 | R             | EXT_SLV_SENS_DATA_21[7:0] |      |                |                 |                   |                |                |               |  |
| 51            | 81             | EXT_SLV_SENS_DATA_22 | R             | EXT_SLV_SENS_DATA_22[7:0] |      |                |                 |                   |                |                |               |  |
| 52            | 82             | EXT_SLV_SENS_DATA_23 | R             | EXT_SLV_SENS_DATA_23[7:0] |      |                |                 |                   |                |                |               |  |
| 66            | 102            | FIFO_EN_1            | R/W           | -                         |      |                |                 | SLV_3_FIFO_EN     | SLV_2_FIFO_EN  | SLV_1_FIFO_EN  | SLV_0_FIFO_EN |  |
| 67            | 103            | FIFO_EN_2            | R/W           | -                         |      |                | ACCEL_FIFO_EN   | GYRO_Z_FIFO_EN    | GYRO_Y_FIFO_EN | GYRO_X_FIFO_EN | TEMP_FIFO_EN  |  |
| 68            | 104            | FIFO_RST             | R/W           | -                         |      |                | FIFO_RESET[4:0] |                   |                |                |               |  |
| 69            | 105            | FIFO_MODE            | R/W           | -                         |      |                | FIFO_MODE[4:0]  |                   |                |                |               |  |
| 70            | 112            | FIFO_COUNTH          | R             | -                         |      |                | FIFO_CNT[12:8]  |                   |                |                |               |  |
| 71            | 113            | FIFO_COUNTL          | R             | FIFO_CNT[7:0]             |      |                |                 |                   |                |                |               |  |
| 72            | 114            | FIFO_R_W             | R/W           | FIFO_R_W[7:0]             |      |                |                 |                   |                |                |               |  |
| 74            | 116            | DATA_RDY_STATUS      | R/C           | WOF_STATU<br>S            | -    |                |                 | RAW_DATA_RDY[3:0] |                |                |               |  |
| 76            | 118            | FIFO_CFG             | R/W           | -                         |      |                |                 |                   |                |                | FIFO_CFG      |  |
| 7F            | 127            | REG_BANK_SEL         | R/W           | -                         |      | USER_BANK[1:0] |                 | -                 |                |                |               |  |

## 7.2 USER BANK 1 REGISTER MAP

| Addr (Hex) | Addr (Dec.) | Register Name     | Serial I/F | Bit7             | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|------------|-------------|-------------------|------------|------------------|------|------|------|------|------|------|------|
| 02         | 2           | SELF_TEST_X_GYRO  | R/W        | XG_ST_DATA[7:0]  |      |      |      |      |      |      |      |
| 03         | 3           | SELF_TEST_Y_GYRO  | R/W        | YG_ST_DATA[7:0]  |      |      |      |      |      |      |      |
| 04         | 4           | SELF_TEST_Z_GYRO  | R/W        | ZG_ST_DATA[7:0]  |      |      |      |      |      |      |      |
| 0E         | 14          | SELF_TEST_X_ACCEL | R/W        | XA_ST_DATA[7:0]  |      |      |      |      |      |      |      |
| 0F         | 15          | SELF_TEST_Y_ACCEL | R/W        | YA_ST_DATA[7:0]  |      |      |      |      |      |      |      |
| 10         | 16          | SELF_TEST_Z_ACCEL | R/W        | ZA_ST_DATA[7:0]  |      |      |      |      |      |      |      |
| 14         | 20          | XA_OFFSETS_H      | R/W        | XA_OFFSETS[14:7] |      |      |      |      |      |      |      |
| 15         | 21          | XA_OFFSETS_L      | R/W        | XA_OFFSETS[6:0]  |      |      |      |      |      |      |      |
| 17         | 23          | YA_OFFSETS_H      | R/W        | YA_OFFSETS[14:7] |      |      |      |      |      |      |      |
| 18         | 24          | YA_OFFSETS_L      | R/W        | YA_OFFSETS[6:0]  |      |      |      |      |      |      |      |
| 1A         | 26          | ZA_OFFSETS_H      | R/W        | ZA_OFFSETS[14:7] |      |      |      |      |      |      |      |
| 1B         | 27          | ZA_OFFSETS_L      | R/W        | ZA_OFFSETS[6:0]  |      |      |      |      |      |      |      |

| Addr (Hex) | Addr (Dec.) | Register Name               | Serial I/F | Bit7         | Bit6 | Bit5           | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|------------|-------------|-----------------------------|------------|--------------|------|----------------|------|------|------|------|------|
| 28         | 40          | TIMEBASE_CORRECTIO<br>N_PLL | R/W        | TBC_PLL[7:0] |      |                |      |      |      |      |      |
| 7F         | 127         | REG_BANK_SEL                | R/W        | -            |      | USER_BANK[1:0] |      | -    |      |      |      |

## 7.3 USER BANK 2 REGISTER MAP

| ADDR<br>(HEX) | ADDR<br>(DEC.) | REGISTER NAME       | SERIAL<br>I/F | BIT7                   | BIT6 | BIT5                | BIT4             | BIT3                    | BIT2              | BIT1          | BIT0                |                           |
|---------------|----------------|---------------------|---------------|------------------------|------|---------------------|------------------|-------------------------|-------------------|---------------|---------------------|---------------------------|
| 00            | 0              | GYRO_SMP_LRT_DIV    | R/W           | GYRO_SMP_LRT_DIV[7:0]  |      |                     |                  |                         |                   |               |                     |                           |
| 01            | 1              | GYRO_CONFIG_1       | R/W           | -                      |      | GYRO_DLPCFG[2:0]    |                  |                         | GYRO_FS_SEL[1:0]  |               | GYRO_FCHOI<br>CE    |                           |
| 02            | 2              | GYRO_CONFIG_2       | R/W           | -                      |      | XGYRO_CTEN          | YGYRO_CTEN       | ZGYRO_CTEN              | GYRO_AVGCFG[2:0]  |               |                     |                           |
| 03            | 3              | XG_OFFS_USRH        | R/W           | X_OFFS_USER[15:8]      |      |                     |                  |                         |                   |               |                     |                           |
| 04            | 4              | XG_OFFS_USRL        | R/W           | X_OFFS_USER[7:0]       |      |                     |                  |                         |                   |               |                     |                           |
| 05            | 5              | YG_OFFS_USRH        | R/W           | Y_OFFS_USER[15:8]      |      |                     |                  |                         |                   |               |                     |                           |
| 06            | 6              | YG_OFFS_USRL        | R/W           | Y_OFFS_USER[7:0]       |      |                     |                  |                         |                   |               |                     |                           |
| 07            | 7              | ZG_OFFS_USRH        | R/W           | Z_OFFS_USER[15:8]      |      |                     |                  |                         |                   |               |                     |                           |
| 08            | 8              | ZG_OFFS_USRL        | R/W           | Z_OFFS_USER[7:0]       |      |                     |                  |                         |                   |               |                     |                           |
| 09            | 9              | ODR_ALIGN_EN        | R/W           | -                      |      |                     |                  |                         |                   |               | ODR_ALIGN_<br>EN    |                           |
| 10            | 16             | ACCEL_SMP_LRT_DIV_1 | R/W           | -                      |      |                     |                  | ACCEL_SMP_LRT_DIV[11:8] |                   |               |                     |                           |
| 11            | 17             | ACCEL_SMP_LRT_DIV_2 | R/W           | ACCEL_SMP_LRT_DIV[7:0] |      |                     |                  |                         |                   |               |                     |                           |
| 12            | 18             | ACCEL_INTEL_CTRL    | R/W           | -                      |      |                     |                  |                         |                   |               | ACCEL_INTEL_<br>_EN | ACCEL_INTEL_<br>_MODE_INT |
| 13            | 19             | ACCEL_WOM_THR       | R/W           | WOM_THRESHOLD[7:0]     |      |                     |                  |                         |                   |               |                     |                           |
| 14            | 20             | ACCEL_CONFIG        | R/W           | -                      |      | ACCEL_DLPCFG[2:0]   |                  |                         | ACCEL_FS_SEL[1:0] |               | ACCEL_FCHOI<br>CE   |                           |
| 15            | 21             | ACCEL_CONFIG_2      | R/W           | -                      |      |                     | AX_ST_EN_R<br>EG | AY_ST_EN_R<br>EG        | AZ_ST_EN_R<br>EG  | DEC3_CFG[1:0] |                     |                           |
| 52            | 82             | FSYNC_CONFIG        | R/W           | DELAY_TIME<br>_EN      | -    | WOF DEGLIT<br>CH_EN | WOF_EDGE_I<br>NT | EXT_SYNC_SET[3:0]       |                   |               |                     |                           |
| 53            | 83             | TEMP_CONFIG         | R/W           | -                      |      |                     |                  |                         | TEMP_DLPCFG[2:0]  |               |                     |                           |
| 54            | 84             | MOD_CTRL_USR        | R/W           | -                      |      |                     |                  |                         |                   |               | REG_LP_DMP<br>_EN   |                           |
| 7F            | 127            | REG_BANK_SEL        | R/W           | -                      |      | USER_BANK[1:0]      |                  | -                       |                   |               |                     |                           |

## 7.4 USER BANK 3 REGISTER MAP

| ADDR<br>(HEX) | ADDR<br>(DEC.) | REGISTER NAME      | SERIAL<br>I/F | BIT7              | BIT6             | BIT5             | BIT4              | BIT3                    | BIT2              | BIT1              | BIT0              |
|---------------|----------------|--------------------|---------------|-------------------|------------------|------------------|-------------------|-------------------------|-------------------|-------------------|-------------------|
| 00            | 0              | I2C_MST_ODR_CONFIG | R/W           | -                 |                  |                  |                   | I2C_MST_ODR_CONFIG[3:0] |                   |                   |                   |
| 01            | 1              | I2C_MST_CTRL       | R/W           | MULT_MST_EN       | -                |                  | I2C_MST_P_NSR     | I2C_MST_CLK[3:0]        |                   |                   |                   |
| 02            | 2              | I2C_MST_DELAY_CTRL | R/W           | DELAY_ES_SHADOW   | -                |                  | I2C_SLV4_DELAY_EN | I2C_SLV3_DELAY_EN       | I2C_SLV2_DELAY_EN | I2C_SLV1_DELAY_EN | I2C_SLV0_DELAY_EN |
| 03            | 3              | I2C_SLV0_ADDR      | R/W           | I2C_SLV0_RNW      | I2C_ID_0[6:0]    |                  |                   |                         |                   |                   |                   |
| 04            | 4              | I2C_SLV0_REG       | R/W           | I2C_SLV0_REG[7:0] |                  |                  |                   |                         |                   |                   |                   |
| 05            | 5              | I2C_SLV0_CTRL      | R/W           | I2C_SLV0_EN       | I2C_SLV0_BYTE_SW | I2C_SLV0_REG_DIS | I2C_SLV0_GRP      | I2C_SLV0_LEN[3:0]       |                   |                   |                   |
| 06            | 6              | I2C_SLV0_DO        | R/W           | I2C_SLV0_DO[7:0]  |                  |                  |                   |                         |                   |                   |                   |
| 07            | 7              | I2C_SLV1_ADDR      | R/W           | I2C_SLV1_RNW      | I2C_ID_1[6:0]    |                  |                   |                         |                   |                   |                   |
| 08            | 8              | I2C_SLV1_REG       | R/W           | I2C_SLV1_REG[7:0] |                  |                  |                   |                         |                   |                   |                   |
| 09            | 9              | I2C_SLV1_CTRL      | R/W           | I2C_SLV1_EN       | I2C_SLV1_BYTE_SW | I2C_SLV1_REG_DIS | I2C_SLV1_GRP      | I2C_SLV1_LEN[3:0]       |                   |                   |                   |

| ADDR (HEX) | ADDR (DEC.) | REGISTER NAME | SERIAL I/F | BIT7              | BIT6              | BIT5              | BIT4              | BIT3               | BIT2 | BIT1 | BIT0 |
|------------|-------------|---------------|------------|-------------------|-------------------|-------------------|-------------------|--------------------|------|------|------|
| 0A         | 10          | I2C_SLV1_DO   | R/W        | I2C_SLV1_DO[7:0]  |                   |                   |                   |                    |      |      |      |
| 0B         | 11          | I2C_SLV2_ADDR | R/W        | I2C_SLV2_RN W     | I2C_ID_2[6:0]     |                   |                   |                    |      |      |      |
| 0C         | 12          | I2C_SLV2_REG  | R/W        | I2C_SLV2_REG[7:0] |                   |                   |                   |                    |      |      |      |
| 0D         | 13          | I2C_SLV2_CTRL | R/W        | I2C_SLV2_EN       | I2C_SLV2_BY TE_SW | I2C_SLV2_RE G_DIS | I2C_SLV2_GR P     | I2C_SLV2 LENG[3:0] |      |      |      |
| 0E         | 14          | I2C_SLV2_DO   | R/W        | I2C_SLV2_DO[7:0]  |                   |                   |                   |                    |      |      |      |
| 0F         | 15          | I2C_SLV3_ADDR | R/W        | I2C_SLV3_RN W     | I2C_ID_3[6:0]     |                   |                   |                    |      |      |      |
| 10         | 16          | I2C_SLV3_REG  | R/W        | I2C_SLV3_REG[7:0] |                   |                   |                   |                    |      |      |      |
| 11         | 17          | I2C_SLV3_CTRL | R/W        | I2C_SLV3_EN       | I2C_SLV3_BY TE_SW | I2C_SLV3_RE G_DIS | I2C_SLV3_GR P     | I2C_SLV3 LENG[3:0] |      |      |      |
| 12         | 18          | I2C_SLV3_DO   | R/W        | I2C_SLV3_DO[7:0]  |                   |                   |                   |                    |      |      |      |
| 13         | 19          | I2C_SLV4_ADDR | R/W        | I2C_SLV4_RN W     | I2C_ID_4[6:0]     |                   |                   |                    |      |      |      |
| 14         | 20          | I2C_SLV4_REG  | R/W        | I2C_SLV4_REG[7:0] |                   |                   |                   |                    |      |      |      |
| 15         | 21          | I2C_SLV4_CTRL | R/W        | I2C_SLV4_EN       | I2C_SLV4_BY TE_SW | I2C_SLV4_RE G_DIS | I2C_SLV4_DLY[4:0] |                    |      |      |      |
| 16         | 22          | I2C_SLV4_DO   | R/W        | I2C_SLV4_DO[7:0]  |                   |                   |                   |                    |      |      |      |
| 17         | 23          | I2C_SLV4_DI   | R          | I2C_SLV4_DI[7:0]  |                   |                   |                   |                    |      |      |      |
| 7F         | 127         | REG_BANK_SEL  | R/W        | -                 |                   | USER_BANK[1:0]    |                   | -                  |      |      |      |

## 8 USER BANK 0 REGISTER DESCRIPTIONS

This section describes the function and contents of the User Bank 0 Register Map within the ICM-20948.

**NOTE:** The device will come up in sleep mode upon power-up.

### 8.1 WHO\_AM\_I

| <b>Name:</b> WHO_AM_I<br><b>Address:</b> 0 (00h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0xEA |               |  |
|--|---------------|--|
| BIT  | NAME          | FUNCTION   |
| 7:0  | WHO_AM_I[7:0] | Register to indicate to user which device is being accessed.<br>The value for ICM-20948 is 0xEA. |

### 8.2 USER\_CTRL

| <b>Name:</b> USER_CTRL<br><b>Address:</b> 3 (03h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |             |   |
|---|-------------|---|
| BIT   | NAME        | FUNCTION  |
| 7   | DMP_EN      | 1 – Enables DMP features.<br>0 – DMP features are disabled after the current processing round has completed.  |
| 6   | FIFO_EN     | 1 – Enable FIFO operation mode.<br>0 – Disable FIFO access from serial interface.<br>To disable FIFO writes by DMA, use FIFO_EN register. To disable possible FIFO writes from DMP, disable the DMP.  |
| 5   | I2C_MST_EN  | 1 – Enable the I <sup>2</sup> C Master I/F module; pins ES_DA and ES_SCL are isolated from pins SDA/SDI and SCL/ SCLK.<br>0 – Disable I <sup>2</sup> C Master I/F module; pins ES_DA and ES_SCL are logically driven by pins SDA/SDI and SCL/ SCLK.   |
| 4   | I2C_IF_DIS  | 1 – Reset I <sup>2</sup> C Slave module and put the serial interface in SPI mode only.  |
| 3   | DMP_RST     | 1 – Reset DMP module. Reset is asynchronous. This bit auto clears after one clock cycle of the internal 20 MHz clock.   |
| 2   | SRAM_RST    | 1 – Reset SRAM module. Reset is asynchronous. This bit auto clears after one clock cycle of the internal 20 MHz clock.  |
| 1   | I2C_MST_RST | 1 – Reset I <sup>2</sup> C Master module. Reset is asynchronous. This bit auto clears after one clock cycle of the internal 20 MHz clock.<br><b>NOTE:</b> This bit should only be set when the I <sup>2</sup> C master has hung. If this bit is set during an active I <sup>2</sup> C master transaction, the I <sup>2</sup> C slave will hang, which will require the host to reset the slave. |
| 0   | -           | Reserved.   |

### 8.3 LP\_CONFIG

| <b>Name:</b> LP_CONFIG<br><b>Address:</b> 5 (05h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x40 |               |   |
|---|---------------|---|
| BIT   | NAME          | FUNCTION  |
| 7   | -             | Reserved.   |
| 6   | I2C_MST_CYCLE | 1 - Operate I <sup>2</sup> C master in duty cycled mode. ODR is determined by I2C_MST_ODR_CONFIG register.<br>0 - Disable I <sup>2</sup> C master duty cycled mode. |
| 5   | ACCEL_CYCLE   | 1 - Operate ACCEL in duty cycled mode. ODR is determined by ACCEL_SMPLRT_DIV register.<br>0 - Disable ACCEL duty cycled mode.                                       |
| 4   | GYRO_CYCLE    | 1 - Operate GYRO in duty cycled mode. ODR is determined by GYRO_SMPLRT_DIV register.<br>0 - Disable GYRO duty cycled mode.  |
| 3:0   | -             | Reserved.   |

### 8.4 PWR\_MGMT\_1

| <b>Name:</b> PWR_MGMT_1<br><b>Address:</b> 6 (06h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x41 |              |  |
|--|--------------|--|
| BIT  | NAME         | FUNCTION   |
| 7  | DEVICE_RESET | 1 - Reset the internal registers and restores the default settings. Write a 1 to set the reset, the bit will auto clear.   |
| 6  | SLEEP        | When set, the chip is set to sleep mode (in sleep mode all analog is powered off). Clearing the bit wakes the chip from sleep mode.  |
| 5  | LP_EN        | The LP_EN only affects the digital circuitry, it helps to reduce the digital current when sensors are in LP mode. Please note that the sensors themselves are set in LP mode by the LP_CONFIG register settings. Sensors in LP mode, and use of LP_EN bit together help to reduce overall current. The bit settings are:<br>1: Turn on low power feature.<br>0: Turn off low power feature.<br>LP_EN has no effect when the sensors are in low-noise mode. |
| 4  | -            | Reserved.  |
| 3  | TEMP_DIS     | When set to 1, this bit disables the temperature sensor.   |
| 2:0  | CLKSEL[2:0]  | <b>Code: Clock Source</b><br>0: Internal 20 MHz oscillator<br>1-5: Auto selects the best available clock source - PLL if ready, else use the Internal oscillator<br>6: Internal 20 MHz oscillator<br>7: Stops the clock and keeps timing generator in reset<br><b>NOTE:</b> CLKSEL[2:0] should be set to 1~5 to achieve full gyroscope performance.  |

## 8.5 PWR\_MGMT\_2

| <b>Name:</b> PWR_MGMT_2<br><b>Address:</b> 7 (07h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|--|---------------|---|
| BIT  | NAME          | FUNCTION  |
| 7:6  | -             | Reserved.   |
| 5:3  | DISABLE_ACCEL | Only the following values are applicable:<br>111 – Accelerometer (all axes) disabled.<br>000 – Accelerometer (all axes) on. |
| 2:0  | DISABLE_GYRO  | Only the following values are applicable:<br>111 – Gyroscope (all axes) disabled.<br>000 – Gyroscope (all axes) on.         |

## 8.6 INT\_PIN\_CFG

| <b>Name:</b> INT_PIN_CFG<br><b>Address:</b> 15 (0Fh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |   |
|--|-------------------|---|
| BIT  | NAME              | FUNCTION  |
| 7  | INT1_ACTL         | 1 – The logic level for INT1 pin is active low.<br>0 – The logic level for INT1 pin is active high.   |
| 6  | INT1_OPEN         | 1 – INT1 pin is configured as open drain.<br>0 – INT1 pin is configured as push-pull.   |
| 5  | INT1_LATCH__EN    | 1 – INT1 pin level held until interrupt status is cleared.<br>0 – INT1 pin indicates interrupt pulse is width 50 $\mu$ s.   |
| 4  | INT_ANYRD_2CLEAR  | 1 – Interrupt status in INT_STATUS is cleared (set to 0) if any read operation is performed.<br>0 – Interrupt status in INT_STATUS is cleared (set to 0) only by reading INT_STATUS register.<br>This bit only affects the interrupt status bits that are contained in the register INT_STATUS, and the corresponding hardware interrupt.<br>This bit does not affect the interrupt status bits that are contained in registers INT_STATUS_1, INT_STATUS_2, INT_STATUS_3, and the corresponding hardware interrupt. |
| 3  | ACTL_FSYNC        | 1 – The logic level for the FSYNC pin as an interrupt to the ICM-20948 is active low.<br>0 – The logic level for the FSYNC pin as an interrupt to the ICM-20948 is active high.   |
| 2  | FSYNC_INT_MODE_EN | 1 – This enables the FSYNC pin to be used as an interrupt. A transition to the active level described by the ACTL_FSYNC bit will cause an interrupt. The status of the interrupt is read in the I <sup>2</sup> C Master Status register PASS_THROUGH bit.<br>0 – This disables the FSYNC pin from causing an interrupt.   |
| 1  | BYPASS_EN         | When asserted, the I <sup>2</sup> C_MASTER interface pins (ES_CL and ES_DA) will go into 'bypass mode' when the I <sup>2</sup> C master interface is disabled.  |
| 0  | -                 | Reserved.   |

## 8.7 INT\_ENABLE

| <b>Name:</b> INT_ENABLE<br><b>Address:</b> 16 (10h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                |   |
|---|----------------|---|
| BIT   | NAME           | FUNCTION  |
| 7   | REG_WOF_EN     | 1 – Enable wake on FSYNC interrupt.<br>0 – Function is disabled.  |
| 6:4   | -              | Reserved.   |
| 3   | WOM_INT_EN     | 1 – Enable interrupt for wake on motion to propagate to interrupt pin 1.<br>0 – Function is disabled.   |
| 2   | PLL_RDY_EN     | 1 – Enable PLL RDY interrupt (PLL RDY means PLL is running and in use as the clock source for the system) to propagate to interrupt pin 1.<br>0 – Function is disabled. |
| 1   | DMP_INT1_EN    | 1 – Enable DMP interrupt to propagate to interrupt pin 1.<br>0 – Function is disabled.  |
| 0   | I2C_MST_INT_EN | 1 – Enable I <sup>2</sup> C master interrupt to propagate to interrupt pin 1.<br>0 – Function is disabled.  |

## 8.8 INT\_ENABLE\_1

| <b>Name:</b> INT_ENABLE_1<br><b>Address:</b> 17 (11h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION  |
| 7:1   | -                 | Reserved.   |
| 0   | RAW_DATA_0_RDY_EN | 1 – Enable raw data ready interrupt from any sensor to propagate to interrupt pin 1.<br>0 – Function is disabled. |

## 8.9 INT\_ENABLE\_2

| <b>Name:</b> INT_ENABLE_2<br><b>Address:</b> 18 (12h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                       |  |
|---|-----------------------|--|
| BIT   | NAME                  | FUNCTION   |
| 7:5   | -                     | Reserved.  |
| 4:0   | FIFO_OVERFLOW_EN[4:0] | 1 – Enable interrupt for FIFO overflow to propagate to interrupt pin 1.<br>0 – Function is disabled. |

### 8.10 INT\_ENABLE\_3

| <b>Name:</b> INT_ENABLE_3<br><b>Address:</b> 19 (13h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                 |   |
|---|-----------------|---|
| BIT   | NAME            | FUNCTION  |
| 7:5   | -               | Reserved.   |
| 4:0   | FIFO_WM_EN[4:0] | 1 – Enable interrupt for FIFO watermark to propagate to interrupt pin 1.<br>0 – Function is disabled. |

### 8.11 I2C\_MST\_STATUS

| <b>Name:</b> I2C_MST_STATUS<br><b>Address:</b> 23 (17h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/C<br><b>Reset Value:</b> 0x00 |               |  |
|---|---------------|--|
| BIT   | NAME          | FUNCTION   |
| 7   | PASS_THROUGH  | Status of FSYNC interrupt – used as a way to pass an external interrupt through this chip to the host. If enabled in the INT_PIN_CFG register by asserting bit FSYNC_INT_MODE_EN, this will cause an interrupt. A read of this register clears all status bits in this register. |
| 6   | I2C_SLV4_DONE | Asserted when I <sup>2</sup> C slave 4's transfer is complete, will cause an interrupt if bit I2C_MST_INT_EN in the INT_ENABLE register is asserted, and if the SLV4_DONE_INT_EN bit is asserted in the I2C_SLV4_CTRL register.  |
| 5   | I2C_LOST_ARB  | Asserted when I <sup>2</sup> C slave loses arbitration of the I <sup>2</sup> C bus, will cause an interrupt if bit I2C_MST_INT_EN in the INT_ENABLE register is asserted.  |
| 4   | I2C_SLV4_NACK | Asserted when slave 4 receives a NACK, will cause an interrupt if bit I2C_MST_INT_EN in the INT_ENABLE register is asserted.   |
| 3   | I2C_SLV3_NACK | Asserted when slave 3 receives a NACK, will cause an interrupt if bit I2C_MST_INT_EN in the INT_ENABLE register is asserted.   |
| 2   | I2C_SLV2_NACK | Asserted when slave 2 receives a NACK, will cause an interrupt if bit I2C_MST_INT_EN in the INT_ENABLE register is asserted.   |
| 1   | I2C_SLV1_NACK | Asserted when slave 1 receives a NACK, will cause an interrupt if bit I2C_MST_INT_EN in the INT_ENABLE register is asserted.   |
| 0   | I2C_SLV0_NACK | Asserted when slave 0 receives a NACK, will cause an interrupt if bit I2C_MST_INT_EN in the INT_ENABLE register is asserted.   |

### 8.12 INT\_STATUS

| <b>Name:</b> INT_STATUS<br><b>Address:</b> 25 (19h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/C<br><b>Reset Value:</b> 0x00 |             |  |
|---|-------------|--|
| BIT   | NAME        | FUNCTION   |
| 7:4   | -           | Reserved.  |
| 3   | WOM_INT     | 1 – Wake on motion interrupt occurred.   |
| 2   | PLL_RDY_INT | 1 – Indicates that the PLL has been enabled and is ready (delay of 4 ms ensures lock). |
| 1   | DMP_INT1    | 1 – Indicates the DMP has generated INT1 interrupt.                                    |
| 0   | I2C_MST_INT | 1 – Indicates I <sup>2</sup> C master has generated an interrupt.                      |



### 8.13 INT\_STATUS\_1

| <b>Name:</b> INT_STATUS_1<br><b>Address:</b> 26 (1Ah)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/C<br><b>Reset Value:</b> 0x00 |                    |  |
|---|--------------------|--|
| BIT   | NAME               | FUNCTION   |
| 7:1   | -                  | Reserved.  |
| 0   | RAW_DATA_0_RDY_INT | 1 – Sensor Register Raw Data, from all sensors, is updated and ready to be read. |

### 8.14 INT\_STATUS\_2

| <b>Name:</b> INT_STATUS_2<br><b>Address:</b> 27 (1Bh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/C<br><b>Reset Value:</b> 0x00 |                        |                                       |
|---|------------------------|---------------------------------------|
| BIT   | NAME                   | FUNCTION                              |
| 7:5   | -                      | Reserved.                             |
| 4:0   | FIFO_OVERFLOW_INT[4:0] | 1 – FIFO Overflow interrupt occurred. |

### 8.15 INT\_STATUS\_3

| <b>Name:</b> INT_STATUS_3<br><b>Address:</b> 28 (1Ch)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/C<br><b>Reset Value:</b> 0x00 |                  |  |
|---|------------------|--|
| BIT   | NAME             | FUNCTION                                   |
| 7:5   | -                | Reserved.                                  |
| 4:0   | FIFO_WM_INT[4:0] | 1 – Watermark interrupt for FIFO occurred. |

### 8.16 DELAY\_TIMEH

| <b>Name:</b> DELAY_TIMEH<br><b>Address:</b> 40 (28h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |   |
|--|------------------|---|
| BIT  | NAME             | FUNCTION  |
| 7:0  | DELAY_TIMEH[7:0] | High-byte of delay time between FSYNC event and the 1st gyro ODR event (after the FSYNC event).<br>Reading DELAY_TIMEH will lock DELAY_TIMEH and DELAY_TIMEL from the next update. Reading DELAY_TIMEL will unlock DELAY_TIMEH and DELAY_TIMEL to take the next update due to an FSYNC event. |

## 8.17 DELAY\_TIMEL

| <b>Name:</b> DELAY_TIMEL<br><b>Address:</b> 41 (29h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION   |
| 7:0  | DELAY_TIMEL[7:0] | Low-byte of delay time between FSYNC event and the 1st gyro ODR event (after the FSYNC event).<br>Reading DELAY_TIMEH will lock DELAY_TIMEH and DELAY_TIMEL from the next update. Reading DELAY_TIMEL will unlock DELAY_TIMEH and DELAY_TIMEL to take the next update due to an FSYNC event.<br>Delay time in $\mu\text{s}$ = (DELAY_TIMEH * 256 + DELAY_TIMEL) * 0.9645 |

## 8.18 ACCEL\_XOUT\_H

| <b>Name:</b> ACCEL_XOUT_H<br><b>Address:</b> 45 (2Dh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION                                |
| 7:0   | ACCEL_XOUT_H[7:0] | High Byte of Accelerometer X-axis data. |

## 8.19 ACCEL\_XOUT\_L

| <b>Name:</b> ACCEL_XOUT_L<br><b>Address:</b> 46 (2Eh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION  |
| 7:0   | ACCEL_XOUT_L[7:0] | Low Byte of Accelerometer X-axis data.<br>To convert the output of the accelerometer to acceleration measurement use the formula below:<br>$X\_acceleration = ACCEL\_XOUT / Accel\_Sensitivity$ |

## 8.20 ACCEL\_YOUT\_H

| <b>Name:</b> ACCEL_YOUT_H<br><b>Address:</b> 47 (2Fh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION                                |
| 7:0   | ACCEL_YOUT_H[7:0] | High Byte of Accelerometer Y-axis data. |

## 8.21 ACCEL\_YOUT\_L

| <b>Name:</b> ACCEL_YOUT_L<br><b>Address:</b> 48 (30h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION  |
| 7:0   | ACCEL_YOUT_L[7:0] | Low Byte of Accelerometer Y-axis data.<br>To convert the output of the accelerometer to acceleration measurement use the formula below:<br>$Y\_acceleration = ACCEL\_YOUT / Accel\_Sensitivity$ |

## 8.22 ACCEL\_ZOUT\_H

| <b>Name:</b> ACCEL_ZOUT_H<br><b>Address:</b> 49 (31h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION                                |
| 7:0   | ACCEL_ZOUT_H[7:0] | High Byte of Accelerometer Z-axis data. |

## 8.23 ACCEL\_ZOUT\_L

| <b>Name:</b> ACCEL_ZOUT_L<br><b>Address:</b> 50 (32h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION  |
| 7:0   | ACCEL_ZOUT_L[7:0] | Low Byte of Accelerometer Z-axis data.<br>To convert the output of the accelerometer to acceleration measurement use the formula below:<br>$Z\_acceleration = ACCEL\_ZOUT / Accel\_Sensitivity$ |

## 8.24 GYRO\_XOUT\_H

| <b>Name:</b> GYRO_XOUT_H<br><b>Address:</b> 51 (33h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |                                     |
|--|------------------|-------------------------------------|
| BIT  | NAME             | FUNCTION                            |
| 7:0  | GYRO_XOUT_H[7:0] | High Byte of Gyroscope X-axis data. |

## 8.25 GYRO\_XOUT\_L

| <b>Name:</b> GYRO_XOUT_L<br><b>Address:</b> 52 (34h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION   |
| 7:0  | GYRO_XOUT_L[7:0] | Low Byte of Gyroscope X-axis data.<br>To convert the output of the gyroscope to angular rate measurement use the formula below:<br>$X\_angular\_rate = GYRO\_XOUT / Gyro\_Sensitivity$ |

## 8.26 GYRO\_YOUT\_H

| <b>Name:</b> GYRO_YOUT_H<br><b>Address:</b> 53 (35h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |                                     |
|--|------------------|-------------------------------------|
| BIT  | NAME             | FUNCTION                            |
| 7:0  | GYRO_YOUT_H[7:0] | High Byte of Gyroscope Y-axis data. |

## 8.27 GYRO\_YOUT\_L

| <b>Name:</b> GYRO_YOUT_L<br><b>Address:</b> 54 (36h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION   |
| 7:0  | GYRO_YOUT_L[7:0] | Low Byte of Gyroscope Y-axis data.<br>To convert the output of the gyroscope to angular rate measurement use the formula below:<br>$Y\_angular\_rate = GYRO\_YOUT / Gyro\_Sensitivity$ |

## 8.28 GYRO\_ZOUT\_H

| <b>Name:</b> GYRO_ZOUT_H<br><b>Address:</b> 55 (37h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |                                     |
|--|------------------|-------------------------------------|
| BIT  | NAME             | FUNCTION                            |
| 7:0  | GYRO_ZOUT_H[7:0] | High Byte of Gyroscope Z-axis data. |

## 8.29 GYRO\_ZOUT\_L

| <b>Name:</b> GYRO_ZOUT_L<br><b>Address:</b> 56 (38h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION   |
| 7:0  | GYRO_ZOUT_L[7:0] | Low Byte of Gyroscope Z-axis data.<br>To convert the output of the gyroscope to angular rate measurement use the formula below:<br>$Z\_angular\_rate = GYRO\_ZOUT / Gyro\_Sensitivity$ |

## 8.30 TEMP\_OUT\_H

| <b>Name:</b> TEMP_OUT_H<br><b>Address:</b> 57 (39h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                 |                                |
|---|-----------------|--------------------------------|
| BIT   | NAME            | FUNCTION                       |
| 7:0   | TEMP_OUT_H[7:0] | High Byte of Temp sensor data. |

## 8.31 TEMP\_OUT\_L

| <b>Name:</b> TEMP_OUT_L<br><b>Address:</b> 58 (3Ah)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                 |  |
|---|-----------------|--|
| BIT   | NAME            | FUNCTION   |
| 7:0   | TEMP_OUT_L[7:0] | Low Byte of Temp sensor data.<br>To convert the output of the temperature sensor to degrees C use the following formula:<br>$TEMP\_degC = ((TEMP\_OUT - RoomTemp\_Offset) / Temp\_Sensitivity) + 21degC$ |

## 8.32 EXT\_SLV\_SENS\_DATA\_00

| <b>Name:</b> EXT_SLV_SENS_DATA_00<br><b>Address:</b> 59 (3Bh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_00[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.33 EXT\_SLV\_SENS\_DATA\_01

| <b>Name:</b> EXT_SLV_SENS_DATA_01<br><b>Address:</b> 60 (3Ch)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_01[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.34 EXT\_SLV\_SENS\_DATA\_02

| <b>Name:</b> EXT_SLV_SENS_DATA_02<br><b>Address:</b> 61 (3Dh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_02[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.35 EXT\_SLV\_SENS\_DATA\_03

| <b>Name:</b> EXT_SLV_SENS_DATA_03<br><b>Address:</b> 62 (3Eh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_03[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.36 EXT\_SLV\_SENS\_DATA\_04

| <b>Name:</b> EXT_SLV_SENS_DATA_04<br><b>Address:</b> 63 (3Fh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_04[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.37 EXT\_SLV\_SENS\_DATA\_05

| <b>Name:</b> EXT_SLV_SENS_DATA_05<br><b>Address:</b> 64 (40h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_05[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.38 EXT\_SLV\_SENS\_DATA\_06

| <b>Name:</b> EXT_SLV_SENS_DATA_06<br><b>Address:</b> 65 (41h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_06[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.39 EXT\_SLV\_SENS\_DATA\_07

| <b>Name:</b> EXT_SLV_SENS_DATA_07<br><b>Address:</b> 66 (42h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_07[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.40 EXT\_SLV\_SENS\_DATA\_08

| <b>Name:</b> EXT_SLV_SENS_DATA_08<br><b>Address:</b> 67 (43h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_08[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.41 EXT\_SLV\_SENS\_DATA\_09

| <b>Name:</b> EXT_SLV_SENS_DATA_09<br><b>Address:</b> 68 (44h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_09[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.42 EXT\_SLV\_SENS\_DATA\_10

| <b>Name:</b> EXT_SLV_SENS_DATA_10<br><b>Address:</b> 69 (45h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_10[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.43 EXT\_SLV\_SENS\_DATA\_11

| <b>Name:</b> EXT_SLV_SENS_DATA_11<br><b>Address:</b> 70 (46h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_11[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.44 EXT\_SLV\_SENS\_DATA\_12

| <b>Name:</b> EXT_SLV_SENS_DATA_12<br><b>Address:</b> 71 (47h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_12[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |



## 8.45 EXT\_SLV\_SENS\_DATA\_13

| <b>Name:</b> EXT_SLV_SENS_DATA_13<br><b>Address:</b> 72 (48h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_13[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.46 EXT\_SLV\_SENS\_DATA\_14

| <b>Name:</b> EXT_SLV_SENS_DATA_14<br><b>Address:</b> 73 (49h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_14[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.47 EXT\_SLV\_SENS\_DATA\_15

| <b>Name:</b> EXT_SLV_SENS_DATA_15<br><b>Address:</b> 74 (4Ah)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_15[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.48 EXT\_SLV\_SENS\_DATA\_16

| <b>Name:</b> EXT_SLV_SENS_DATA_16<br><b>Address:</b> 75 (4Bh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_16[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.49 EXT\_SLV\_SENS\_DATA\_17

| <b>Name:</b> EXT_SLV_SENS_DATA_17<br><b>Address:</b> 76 (4Ch)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_17[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.50 EXT\_SLV\_SENS\_DATA\_18

| <b>Name:</b> EXT_SLV_SENS_DATA_18<br><b>Address:</b> 77 (4Dh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_18[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.51 EXT\_SLV\_SENS\_DATA\_19

| <b>Name:</b> EXT_SLV_SENS_DATA_19<br><b>Address:</b> 78 (4Eh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_19[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.52 EXT\_SLV\_SENS\_DATA\_20

| <b>Name:</b> EXT_SLV_SENS_DATA_20<br><b>Address:</b> 79 (4Fh)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_20[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.53 EXT\_SLV\_SENS\_DATA\_21

| <b>Name:</b> EXT_SLV_SENS_DATA_21<br><b>Address:</b> 80 (50h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_21[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.54 EXT\_SLV\_SENS\_DATA\_22

| <b>Name:</b> EXT_SLV_SENS_DATA_22<br><b>Address:</b> 81 (51h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_22[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.55 EXT\_SLV\_SENS\_DATA\_23

| <b>Name:</b> EXT_SLV_SENS_DATA_23<br><b>Address:</b> 82 (52h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                           |   |
|---|---------------------------|---|
| BIT   | NAME                      | FUNCTION  |
| 7:0   | EXT_SLV_SENS_DATA_23[7:0] | Sensor data read from external I <sup>2</sup> C devices via the I <sup>2</sup> C master interface. The data stored is controlled by the I2C_SLV(0-4)_ADDR, I2C_SLV(0-4)_REG, and I2C_SLV(0-4)_CTRL registers. |

## 8.56 FIFO\_EN\_1

| <b>Name:</b> FIFO_EN_1<br><b>Address:</b> 102 (66h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|---|---------------|---|
| BIT   | NAME          | FUNCTION  |
| 7:4   | -             | Reserved.   |
| 3   | SLV_3_FIFO_EN | 1 – Write EXT_SENS_DATA registers associated to SLV_3 (as determined by I2C_SLV2_CTRL, I2C_SLV1_CTRL, and I2C_SL20_CTRL) to the FIFO at the sample rate;<br>0 – Function is disabled. |
| 2   | SLV_2_FIFO_EN | 1 – Write EXT_SENS_DATA registers associated to SLV_2 (as determined by I2C_SLV0_CTRL, I2C_SLV1_CTRL, and I2C_SL20_CTRL) to the FIFO at the sample rate;<br>0 – Function is disabled. |
| 1   | SLV_1_FIFO_EN | 1 – Write EXT_SENS_DATA registers associated to SLV_1 (as determined by I2C_SLV0_CTRL and I2C_SLV1_CTRL) to the FIFO at the sample rate;<br>0 – Function is disabled.                 |
| 0   | SLV_0_FIFO_EN | 1 – Write EXT_SENS_DATA registers associated to SLV_0 (as determined by I2C_SLV0_CTRL) to the FIFO at the sample rate;<br>0 – Function is disabled.                                   |

## 8.57 FIFO\_EN\_2

| <b>Name:</b> FIFO_EN_2<br><b>Address:</b> 103 (67h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                |   |
|---|----------------|---|
| BIT   | NAME           | FUNCTION  |
| 7:5   | -              | Reserved.   |
| 4   | ACCEL_FIFO_EN  | 1 – Write ACCEL_XOUT_H, ACCEL_XOUT_L, ACCEL_YOUT_H, ACCEL_YOUT_L, ACCEL_ZOUT_H, and ACCEL_ZOUT_L to the FIFO at the sample rate;<br>0 – Function is disabled. |
| 3   | GYRO_Z_FIFO_EN | 1 – Write GYRO_ZOUT_H and GYRO_ZOUT_L to the FIFO at the sample rate.<br>0 – Function is disabled.  |
| 2   | GYRO_Y_FIFO_EN | 1 – Write GYRO_YOUT_H and GYRO_YOUT_L to the FIFO at the sample rate.<br>0 – Function is disabled.  |
| 1   | GYRO_X_FIFO_EN | 1 – Write GYRO_XOUT_H and GYRO_XOUT_L to the FIFO at the sample rate.<br>0 – Function is disabled.  |
| 0   | TEMP_FIFO_EN   | 1 – Write TEMP_OUT_H and TEMP_OUT_L to the FIFO at the sample rate.<br>0 – Function is disabled.  |

### 8.58 FIFO\_RST

| <b>Name:</b> FIFO_RST<br><b>Address:</b> 104 (68h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                 |  |
|--|-----------------|--|
| BIT  | NAME            | FUNCTION   |
| 7:5  | -               | Reserved.  |
| 4:0  | FIFO_RESET[4:0] | S/W FIFO reset. Assert and hold to set FIFO size to 0. Assert and de-assert to reset FIFO. |

### 8.59 FIFO\_MODE

| <b>Name:</b> FIFO_MODE<br><b>Address:</b> 105 (69h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                |   |
|---|----------------|---|
| BIT   | NAME           | FUNCTION  |
| 7:5   | -              | Reserved.   |
| 4:0   | FIFO_MODE[4:0] | 0 – Stream.<br>1 – Snapshot.<br>When set to '1', when the FIFO is full, additional writes will not be written to FIFO.<br>When set to '0', when the FIFO is full, additional writes will be written to the FIFO, replacing the oldest data. |

### 8.60 FIFO\_COUNTH

| <b>Name:</b> FIFO_COUNTH<br><b>Address:</b> 112 (70h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |                |  |
|---|----------------|--|
| BIT   | NAME           | FUNCTION   |
| 7:5   | -              | Reserved.  |
| 4:0   | FIFO_CNT[12:8] | High Bits, count indicates the number of written bytes in the FIFO.<br>Reading this byte latches the data for both FIFO_COUNTH, and FIFO_COUNTL. |

### 8.61 FIFO\_COUNTL

| <b>Name:</b> FIFO_COUNTL<br><b>Address:</b> 113 (71h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R<br><b>Reset Value:</b> 0x00 |               |  |
|---|---------------|--|
| BIT   | NAME          | FUNCTION   |
| 7:0   | FIFO_CNT[7:0] | Low bits, count indicates the number of written bytes in the FIFO. |

## 8.62 FIFO\_R\_W

| <b>Name:</b> FIFO_R_W<br><b>Address:</b> 114 (72h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|--|---------------|---|
| BIT  | NAME          | FUNCTION  |
| 7:0  | FIFO_R_W[7:0] | Reading from or writing to this register actually reads/writes the FIFO. For example, to write a byte to the FIFO, write the desired byte value to FIFO_R_W[7:0]. To read a byte from the FIFO, perform a register read operation and access the result in FIFO_R_W[7:0]. |

## 8.63 DATA\_RDY\_STATUS

| <b>Name:</b> DATA_RDY_STATUS<br><b>Address:</b> 116 (74h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/C<br><b>Reset Value:</b> 0x00 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION  |
| 7   | WOF_STATUS        | Wake on FSYNC interrupt status. Cleared on read.  |
| 6:4   | -                 | Reserved.   |
| 3:0   | RAW_DATA_RDY[3:0] | Data from sensors is copied to FIFO or SRAM.<br>Set when sequence controller kicks off on a sensor data load. Only bit 0 is relevant in a single FIFO configuration. Cleared on read. |

## 8.64 FIFO\_CFG

| <b>Name:</b> FIFO_CFG<br><b>Address:</b> 118 (76h)<br><b>Type:</b> USR0<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |          |  |
|--|----------|--|
| BIT  | NAME     | FUNCTION   |
| 7:1  | -        | Reserved.  |
| 0  | FIFO_CFG | This bit should be set to 1 if interrupt status for each sensor is required. |

## 8.65 REG\_BANK\_SEL

| <b>Name:</b> REG_BANK_SEL<br><b>Address:</b> 127 (7Fh)<br><b>Type:</b> ALL<br><b>Bank:</b> 0<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                |   |
|---|----------------|---|
| BIT   | NAME           | FUNCTION  |
| 7:6   | -              | Reserved.   |
| 5:4   | USER_BANK[1:0] | Use the following values in this bit-field to select a USER BANK.<br>0: Select USER BANK 0.<br>1: Select USER BANK 1.<br>2: Select USER BANK 2.<br>3: Select USER BANK 3. |
| 3:0   | -              | Reserved.   |

## 9 USR BANK 1 REGISTER DESCRIPTIONS

This section describes the function and contents of the User Bank 1 Register Map within the ICM-20948.

**NOTE:** The device will come up in sleep mode upon power-up.

### 9.1 SELF\_TEST\_X\_GYRO

| <b>Name:</b> SELF_TEST_X_GYRO<br><b>Address:</b> 2 (02h)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                 |   |
|--|-----------------|---|
| BIT  | NAME            | FUNCTION  |
| 7:0  | XG_ST_DATA[7:0] | The value in this register indicates the self-test output generated during manufacturing tests. This value is to be used to check against subsequent self-test outputs performed by the end user. |

### 9.2 SELF\_TEST\_Y\_GYRO

| <b>Name:</b> SELF_TEST_Y_GYRO<br><b>Address:</b> 3 (03h)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                 |   |
|--|-----------------|---|
| BIT  | NAME            | FUNCTION  |
| 7:0  | YG_ST_DATA[7:0] | The value in this register indicates the self-test output generated during manufacturing tests. This value is to be used to check against subsequent self-test outputs performed by the end user. |

### 9.3 SELF\_TEST\_Z\_GYRO

| <b>Name:</b> SELF_TEST_Z_GYRO<br><b>Address:</b> 4 (04h)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                 |   |
|--|-----------------|---|
| BIT  | NAME            | FUNCTION  |
| 7:0  | ZG_ST_DATA[7:0] | The value in this register indicates the self-test output generated during manufacturing tests. This value is to be used to check against subsequent self-test outputs performed by the end user. |

### 9.4 SELF\_TEST\_X\_ACCEL

| <b>Name:</b> SELF_TEST_X_ACCEL<br><b>Address:</b> 14 (0Eh)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                 |  |
|--|-----------------|--|
| BIT  | NAME            | FUNCTION   |
| 7:0  | XA_ST_DATA[7:0] | Contains self-test data for the X Accelerometer. |

## 9.5 SELF\_TEST\_Y\_ACCEL

**Name:** SELF\_TEST\_Y\_ACCEL

**Address:** 15 (0Fh)

**Type:** USR1

**Bank:** 1

**Serial IF:** R/W

**Reset Value:** 0x00

| BIT | NAME            | FUNCTION   |
|-----|-----------------|--|
| 7:0 | YA_ST_DATA[7:0] | Contains self-test data for the Y Accelerometer. |

## 9.6 SELF\_TEST\_Z\_ACCEL

**Name:** SELF\_TEST\_Z\_ACCEL

**Address:** 16 (10h)

**Type:** USR1

**Bank:** 1

**Serial IF:** R/W

**Reset Value:** 0x00

| BIT | NAME            | FUNCTION   |
|-----|-----------------|--|
| 7:0 | ZA_ST_DATA[7:0] | Contains self-test data for the Z Accelerometer. |

## 9.7 XA\_OFFS\_H

**Name:** XA\_OFFS\_H

**Address:** 20 (14h)

**Type:** USR1

**Bank:** 1

**Serial IF:** R/W

**Reset Value:** Trimmed on a per-part basis for optimal performance

| BIT | NAME          | FUNCTION   |
|-----|---------------|--|
| 7:0 | XA_OFFS[14:7] | Upper bits of the X accelerometer offset cancellation. |

## 9.8 XA\_OFFS\_L

**Name:** XA\_OFFS\_L

**Address:** 21 (15h)

**Type:** USR1

**Bank:** 1

**Serial IF:** R/W

**Reset Value:** Trimmed on a per-part basis for optimal performance

| BIT | NAME         | FUNCTION   |
|-----|--------------|--|
| 7:1 | XA_OFFS[6:0] | Lower bits of the X accelerometer offset cancellation. |
| 0   | -            | Reserved.  |

## 9.9 YA\_OFFS\_H

**Name:** YA\_OFFS\_H

**Address:** 23 (17h)

**Type:** USR1

**Bank:** 1

**Serial IF:** R/W

**Reset Value:** Trimmed on a per-part basis for optimal performance

| BIT | NAME          | FUNCTION   |
|-----|---------------|--|
| 7:0 | YA_OFFS[14:7] | Upper bits of the Y accelerometer offset cancellation. |



### 9.10 YA\_OFFS\_L

| <b>Name:</b> YA_OFFS_L<br><b>Address:</b> 24 (18h)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> Trimmed on a per-part basis for optimal performance |              |  |
|---|--------------|--|
| BIT   | NAME         | FUNCTION   |
| 7:1   | YA_OFFS[6:0] | Lower bits of the Y accelerometer offset cancellation. |
| 0   | -            | Reserved .   |

### 9.11 ZA\_OFFS\_H

| <b>Name:</b> ZA_OFFS_H<br><b>Address:</b> 26 (1Ah)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> Trimmed on a per-part basis for optimal performance |               |  |
|---|---------------|--|
| BIT   | NAME          | FUNCTION   |
| 7:0   | ZA_OFFS[14:7] | Upper bits of the Z accelerometer offset cancellation. |

### 9.12 ZA\_OFFS\_L

| <b>Name:</b> ZA_OFFS_L<br><b>Address:</b> 27 (1Bh)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> Trimmed on a per-part basis for optimal performance |              |  |
|---|--------------|--|
| BIT   | NAME         | FUNCTION   |
| 7:1   | ZA_OFFS[6:0] | Lower bits of the Z accelerometer offset cancellation. |
| 0   | -            | Reserved.  |

### 9.13 TIMEBASE\_CORRECTION\_PLL

| <b>Name:</b> TIMEBASE_CORRECTION_PLL<br><b>Address:</b> 40 (28h)<br><b>Type:</b> USR1<br><b>Bank:</b> 1<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |              |   |
|--|--------------|---|
| BIT  | NAME         | FUNCTION  |
| 7:0  | TBC_PLL[7:0] | System PLL clock period error (signed, [-10%, +10%]). |

## 9.14 REG\_BANK\_SEL

**Name:** REG\_BANK\_SEL

**Address:** 127 (7Fh)

**Type:**

**Bank:** 1

**Serial IF:** R/W

**Reset Value:** 0x00

| BIT | NAME           | FUNCTION  |
|-----|----------------|---|
| 7:6 | -              | Reserved.   |
| 5:4 | USER_BANK[1:0] | Use the following values in this bit-field to select a USER BANK.<br>0: Select USER BANK 0.<br>1: Select USER BANK 1.<br>2: Select USER BANK 2.<br>3: Select USER BANK 3. |
| 3:0 | -              | Reserved.   |

## 10 USR BANK 2 REGISTER MAP

This section describes the function and contents of the User Bank 2 Register Map within the ICM-20948.

**NOTE:** The device will come up in sleep mode upon power-up.

### 10.1 GYRO\_SMPLRT\_DIV

| <b>Name:</b> GYRO_SMPLRT_DIV<br><b>Address:</b> 0 (00h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                      |  |
|---|----------------------|--|
| BIT   | NAME                 | FUNCTION   |
| 7:0   | GYRO_SMPLRT_DIV[7:0] | Gyro sample rate divider. Divides the internal sample rate to generate the sample rate that controls sensor data output rate, FIFO sample rate, and DMP sequence rate.<br><b>NOTE:</b> This register is only effective when FCHOICE = 1'b1 (FCHOICE_B register bit is 1'b0), and (0 < DLPF_CFG < 7).<br>ODR is computed as follows:<br>$1.1 \text{ kHz} / (1 + \text{GYRO\_SMPLRT\_DIV}[7:0])$ |

### 10.2 GYRO\_CONFIG\_1

| <b>Name:</b> GYRO_CONFIG_1<br><b>Address:</b> 1 (01h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x01 |                   |   |
|---|-------------------|---|
| BIT   | NAME              | FUNCTION  |
| 7:6   | -                 | Reserved.   |
| 5:3   | GYRO_DLPFCFG[2:0] | Gyro low pass filter configuration as shown in Table 16.                                      |
| 2:1   | GYRO_FS_SEL[1:0]  | Gyro Full Scale Select:<br>00 = ±250 dps<br>01 = ±500 dps<br>10 = ±1000 dps<br>11 = ±2000 dps |
| 0   | GYRO_FCHOICE      | 0 – Bypass gyro DLPF.<br>1 – Enable gyro DLPF.  |

The gyroscope DLPF is configured by GYRO\_DLPFCFG, when GYRO\_FCHOICE = 1. The gyroscope data is filtered according to the value of GYRO\_DLPFCFG and GYRO\_FCHOICE as shown in Table 16.

| GYRO_FCHOICE | GYRO_DLPFCFG | OUTPUT      |          |  |
|--------------|--------------|-------------|----------|--|
|              |              | 3DB BW [Hz] | NBW [Hz] | RATE [Hz]  |
| 0            | x            | 12106       | 12316    | 9000   |
| 1            | 0            | 196.6       | 229.8    | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |
| 1            | 1            | 151.8       | 187.6    | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |
| 1            | 2            | 119.5       | 154.3    | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |
| 1            | 3            | 51.2        | 73.3     | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |
| 1            | 4            | 23.9        | 35.9     | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |
| 1            | 5            | 11.6        | 17.8     | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |
| 1            | 6            | 5.7         | 8.9      | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |
| 1            | 7            | 361.4       | 376.5    | 1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255 |

**Table 16. Gyroscope Configuration 1**

### 10.3 GYRO\_CONFIG\_2

| <b>Name: GYRO_CONFIG_2</b><br><b>Address: 2 (02h)</b><br><b>Type: USR2</b><br><b>Bank: 2</b><br><b>Serial IF: R/W</b><br><b>Reset Value: 0x00</b> |                  |  |
|---|------------------|--|
| BIT   | NAME             | FUNCTION   |
| 7:6   | -                | Reserved.  |
| 5   | XGYRO_CTEN       | X Gyro self-test enable.   |
| 4   | YGYRO_CTEN       | Y Gyro self-test enable.   |
| 3   | ZGYRO_CTEN       | Z Gyro self-test enable.   |
| 2:0   | GYRO_AVGCFG[2:0] | Averaging filter configuration settings for low-power mode.<br>0: 1x averaging.<br>1: 2x averaging.<br>2: 4x averaging.<br>3: 8x averaging.<br>4: 16x averaging.<br>5: 32x averaging.<br>6: 64x averaging.<br>7: 128x averaging. |

Table 17 lists the gyroscope filter bandwidths available in the low-power mode of operation. In the low-power mode of operation, the gyroscope is duty-cycled.

|                 | AVERAGES   | 1X                           | 2X    | 4X    | 8X    | 16X  | 32X   | 64X   | 128X  |
|-----------------|--|------------------------------|-------|-------|-------|------|-------|-------|-------|
|                 | GYRO_FCHOICE   | 1                            | 1     | 1     | 1     | 1    | 1     | 1     | 1     |
|                 | GYRO_AVGCFG  | 0                            | 1     | 2     | 3     | 4    | 5     | 6     | 7     |
|                 | TON [MS]   | 1.15                         | 1.59  | 2.48  | 4.26  | 7.82 | 14.93 | 29.15 | 57.59 |
|                 | NBW [HZ]   | 773.5                        | 469.8 | 257.8 | 134.8 | 68.9 | 34.8  | 17.5  | 8.8   |
|                 | RMS NOISE<br>[DPS-RMS] TYP<br>(BASED ON GYROSCOPE<br>NOISE: 0.011 DPS/VHZ) | 0.31                         | 0.24  | 0.18  | 0.13  | 0.09 | 0.06  | 0.05  | 0.03  |
| GYRO_SMPLRT_DIV | ODR [HZ]   | CURRENT CONSUMPTION [mA] TYP |       |       |       |      |       |       |       |
| 255             | 4.4  | 1.04                         | 1.05  | 1.05  | 1.06  | 1.09 | 1.14  | 1.24  | 1.45  |
| 64              | 17.3   | 1.07                         | 1.08  | 1.10  | 1.15  | 1.25 | 1.45  | 1.85  | N/A   |
| 63              | 17.6   | 1.07                         | 1.08  | 1.11  | 1.16  | 1.26 | 1.46  | 1.87  |       |
| 32              | 34.1   | 1.10                         | 1.12  | 1.17  | 1.27  | 1.47 | 1.86  | N/A   |       |
| 31              | 35.2   | 1.10                         | 1.13  | 1.18  | 1.28  | 1.48 | 1.89  |       |       |
| 22              | 48.9   | 1.13                         | 1.16  | 1.23  | 1.37  | 1.66 | 2.22  |       |       |
| 16              | 66.2   | 1.16                         | 1.21  | 1.30  | 1.49  | 1.88 |       |       |       |
| 15              | 70.3   | 1.17                         | 1.22  | 1.32  | 1.52  | 1.93 | N/A   |       |       |
| 10              | 102.3  | 1.23                         | 1.30  | 1.45  | 1.74  | 2.34 |       |       |       |
| 8               | 125.0  | 1.27                         | 1.36  | 1.54  | 1.90  |      |       |       |       |
| 7               | 140.6  | 1.30                         | 1.40  | 1.60  | 2.01  | N/A  |       |       |       |
| 5               | 187.5  | 1.38                         | 1.52  | 1.79  | 2.33  |      |       |       |       |
| 4               | 225.0  | 1.45                         | 1.62  | 1.94  |       |      |       |       |       |
| 3               | 281.3  | 1.56                         | 1.76  | 2.17  | N/A   |      |       |       |       |
| 2               | 375.0  | 1.74                         | 2.00  |       |       |      |       |       |       |
| 1               | 562.5  | 2.09                         | N/A   |       |       |      |       |       |       |

**Table 17. Gyroscope Configuration 2**

**NOTE:** Ton is the ON time for motion measurement when the gyroscope is in duty cycle mode.

## 10.4 XG\_OFFS\_USRH

| <b>Name:</b> XG_OFFS_USRH<br><b>Address:</b> 3 (03h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |   |
|--|-------------------|---|
| BIT  | NAME              | FUNCTION                                  |
| 7:0  | X_OFFS_USER[15:8] | Upper byte of X gyro offset cancellation. |

## 10.5 XG\_OFFS\_USRL

| <b>Name:</b> XG_OFFS_USRL<br><b>Address:</b> 4 (04h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |   |
|--|------------------|---|
| BIT  | NAME             | FUNCTION                                  |
| 7:0  | X_OFFS_USER[7:0] | Lower byte of X gyro offset cancellation. |

## 10.6 YG\_OFFS\_USRH

| <b>Name:</b> YG_OFFS_USRH<br><b>Address:</b> 5 (05h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |   |
|--|-------------------|---|
| BIT  | NAME              | FUNCTION                                  |
| 7:0  | Y_OFFS_USER[15:8] | Upper byte of Y gyro offset cancellation. |

## 10.7 YG\_OFFS\_USRL

| <b>Name:</b> YG_OFFS_USRL<br><b>Address:</b> 6 (06h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |   |
|--|------------------|---|
| BIT  | NAME             | FUNCTION                                  |
| 7:0  | Y_OFFS_USER[7:0] | Lower byte of Y gyro offset cancellation. |

## 10.8 ZG\_OFFS\_USRH

| <b>Name:</b> ZG_OFFS_USRH<br><b>Address:</b> 7 (07h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |   |
|--|-------------------|---|
| BIT  | NAME              | FUNCTION                                  |
| 7:0  | Z_OFFS_USER[15:8] | Upper byte of Z gyro offset cancellation. |

## 10.9 ZG\_OFFS\_USRL

| <b>Name:</b> ZG_OFFS_USRL<br><b>Address:</b> 8 (08h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |   |
|--|------------------|---|
| BIT  | NAME             | FUNCTION                                  |
| 7:0  | Z_OFFS_USER[7:0] | Lower byte of Z gyro offset cancellation. |

## 10.10 ODR\_ALIGN\_EN

| <b>Name:</b> ODR_ALIGN_EN<br><b>Address:</b> 9 (09h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>OTP:</b> No<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |              |  |
|--|--------------|--|
| BIT  | NAME         | FUNCTION   |
| 7:1  | -            | Reserved.  |
| 0  | ODR_ALIGN_EN | 0: Disables ODR start-time alignment.<br>1: Enables ODR start-time alignment when any of the following registers is written (with the same value or with different values): GYRO_SMPLRT_DIV, ACCEL_SMPLRT_DIV_1, ACCEL_SMPLRT_DIV_2, I2C_MST_ODR_CONFIG. |

## 10.11 ACCEL\_SMPLRT\_DIV\_1

| <b>Name:</b> ACCEL_SMPLRT_DIV_1<br><b>Address:</b> 16 (10h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                        |                                |
|---|------------------------|--------------------------------|
| BIT   | NAME                   | FUNCTION                       |
| 7:4   | -                      | Reserved.                      |
| 3:0   | ACCEL_SMPLRT_DIV[11:8] | MSB for ACCEL sample rate div. |

## 10.12 ACCEL\_SMPLRT\_DIV\_2

| <b>Name:</b> ACCEL_SMPLRT_DIV_2<br><b>Address:</b> 17 (11h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                       |  |
|---|-----------------------|--|
| BIT   | NAME                  | FUNCTION   |
| 7:0   | ACCEL_SMPLRT_DIV[7:0] | LSB for ACCEL sample rate div.<br>ODR is computed as follows:<br>$1.125 \text{ kHz} / (1 + \text{ACCEL\_SMPLRT\_DIV}[11:0])$ |

## 10.13 ACCEL\_INTEL\_CTRL

| <b>Name:</b> ACCEL_INTEL_CTRL<br><b>Address:</b> 18 (12h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                      |  |
|---|----------------------|--|
| BIT   | NAME                 | FUNCTION   |
| 7:2   | -                    | Reserved.  |
| 1   | ACCEL_INTEL_EN       | Enable the WOM logic.  |
| 0   | ACCEL_INTEL_MODE_INT | Selects WOM algorithm.<br>1 = Compare the current sample with the previous sample.<br>0 = Initial sample is stored, all future samples are compared to the initial sample. |

## 10.14 ACCEL\_WOM\_THR

| <b>Name:</b> ACCEL_WOM_THR<br><b>Address:</b> 19 (13h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                    |  |
|--|--------------------|--|
| BIT  | NAME               | FUNCTION   |
| 7:0  | WOM_THRESHOLD[7:0] | This register holds the threshold value for the Wake on Motion Interrupt for ACCEL x/y/z axes. LSB = 4 mg. Range is 0 mg to 1020 mg. |

## 10.15 ACCEL\_CONFIG

| <b>Name:</b> ACCEL_CONFIG<br><b>Address:</b> 20 (14h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x01 |                    |   |
|---|--------------------|---|
| BIT   | NAME               | FUNCTION  |
| 7:6   | -                  | Reserved.   |
| 5:3   | ACCEL_DLPFCFG[2:0] | Accelerometer low pass filter configuration as shown in Table 18.             |
| 2:1   | ACCEL_FS_SEL[1:0]  | Accelerometer Full Scale Select:<br>00: ±2g<br>01: ±4g<br>10: ±8g<br>11: ±16g |
| 0   | ACCEL_FCHOICE      | 0: Bypass accel DLPF.<br>1: Enable accel DLPF.                                |

| ACCEL_FCHOICE | ACCEL_DLPFCFG | OUTPUT      |          |   |
|---------------|---------------|-------------|----------|---|
|               |               | 3DB BW [HZ] | NBW [HZ] | RATE [HZ]   |
| 0             | x             | 1209        | 1248     | 4500  |
| 1             | 0             | 246.0       | 265.0    | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |
| 1             | 1             | 246.0       | 265.0    | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |
| 1             | 2             | 111.4       | 136.0    | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |
| 1             | 3             | 50.4        | 68.8     | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |
| 1             | 4             | 23.9        | 34.4     | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |
| 1             | 5             | 11.5        | 17.0     | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |
| 1             | 6             | 5.7         | 8.3      | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |
| 1             | 7             | 473         | 499      | 1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095 |

**Table 18. Accelerator Configuration**

The data rate out of the DLPF filter block can be further reduced by a factor of  $1.125 \text{ kHz}/(1+\text{ACCEL\_SMPLRT\_DIV}[11:0])$  where ACCEL\_SMPLRT\_DIV is a 12-bit integer.



## 10.16 ACCEL\_CONFIG\_2

| <b>Name:</b> ACCEL_CONFIG_2<br><b>Address:</b> 21 (15h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |  |
|---|---------------|--|
| BIT   | NAME          | FUNCTION   |
| 7:5   | -             | Reserved.  |
| 4   | AX_ST_EN_REG  | X Accel self-test enable.  |
| 3   | AY_ST_EN_REG  | Y Accel self-test enable.  |
| 2   | AZ_ST_EN_REG  | Z Accel self-test enable.  |
| 1:0   | DEC3_CFG[1:0] | Controls the number of samples averaged in the accelerometer decimator:<br>0: Average 1 or 4 samples depending on ACCEL_FCHOICE (see Table 19).<br>1: Average 8 samples.<br>2: Average 16 samples.<br>3: Average 32 samples. |

Table 19 lists the accelerometer filter bandwidths available in the low-power mode of operation. In the low-power mode of operation, the accelerometer is duty-cycled.

|                  | AVERAGES   | 1X                           | 4X    | 8X    | 16X   | 32X   |
|------------------|--|------------------------------|-------|-------|-------|-------|
|                  | ACCEL_FCHOICE  | 0                            | 1     | 1     | 1     | 1     |
|                  | ACCEL_DLPFCFG  | x                            | 7     | 7     | 7     | 7     |
|                  | DEC3_CFG   | 0                            | 0     | 1     | 2     | 3     |
|                  | TON (MS)   | 0.821                        | 1.488 | 2.377 | 4.154 | 7.71  |
|                  | NBW (HZ)   | 1237.5                       | 496.8 | 264.8 | 136.5 | 69.2  |
|                  | RMS NOISE<br>[MG-RMS] TYP<br>(BASED ON<br>ACCELEROMETER NOISE:<br>190µG/√HZ) | 6.7                          | 4.2   | 3.1   | 2.2   | 1.6   |
| ACCEL_SmplRT_DIV | ODR [HZ]   | CURRENT CONSUMPTION [µA] TYP |       |       |       |       |
| 4095             | 0.27   | 6.2                          | 6.3   | 6.5   | 6.9   | 7.6   |
| 2044             | 0.55   | 6.3                          | 6.6   | 7.0   | 7.7   | 9.2   |
| 1022             | 1.1  | 6.7                          | 7.2   | 8.0   | 9.4   | 12.3  |
| 513              | 2.2  | 7.3                          | 8.4   | 9.9   | 12.8  | 18.6  |
| 255              | 4.4  | 8.7                          | 10.9  | 13.8  | 19.7  | 31.4  |
| 127              | 8.8  | 11.4                         | 15.8  | 21.6  | 33.3  | 56.7  |
| 63               | 17.6   | 16.8                         | 25.6  | 37.3  | 60.7  | 107.5 |
| 31               | 35.2   | 27.6                         | 45.2  | 68.6  | 115.3 | 208.9 |
| 22               | 48.9   | 36.1                         | 60.5  | 93.0  | 158.1 | 288.3 |
| 15               | 70.3   | 49.2                         | 84.3  | 131.1 | 224.7 | 411.9 |
| 10               | 102.3  | 68.9                         | 119.9 | 188.0 | 324.1 | 596.3 |
| 7                | 140.6  | 92.4                         | 162.7 | 256.3 | 443.3 | N/A   |

|   |       |       |       |     |
|---|-------|-------|-------|-----|
| 5 | 187.5 | 121.2 | 214.9 |     |
| 3 | 281.3 | 178.9 | 319.3 | N/A |
| 1 | 562.5 | 351.7 | N/A   |     |

**Table 19. Accelerator Configuration 2**

**NOTE:** Ton is the ON time for motion measurement when the accelerometer is in duty cycle mode.

## 10.17 FSYNC\_CONFIG

| <b>Name:</b> FSYNC_CONFIG<br><b>Address:</b> 82 (52h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |  |
|---|-------------------|--|
| BIT   | NAME              | FUNCTION   |
| 7   | DELAY_TIME_EN     | 0: Disables delay time measurement between FSYNC event and the first ODR event (after FSYNC event).<br>1: Enables delay time measurement between FSYNC event and the first ODR event (after FSYNC event).  |
| 6   | -                 | Reserved.  |
| 5   | WOF_DEGLITCH_EN   | Enable digital deglitching of FSYNC input for Wake on FSYNC.   |
| 4   | WOF_EDGE_INT      | 0: FSYNC is a level interrupt for Wake on FSYNC.<br>1: FSYNC is an edge interrupt for Wake on FSYNC.<br>ACTL_FSYNC is used to set the polarity of the interrupt.   |
| 3:0   | EXT_SYNC_SET[3:0] | Enables the FSYNC pin data to be sampled.<br>EXT_SYNC_SET FSYNC bit location.<br>0: Function disabled.<br>1: TEMP_OUT_L[0].<br>2: GYRO_XOUT_L[0].<br>3: GYRO_YOUT_L[0].<br>4: GYRO_ZOUT_L[0].<br>5: ACCEL_XOUT_L[0].<br>6: ACCEL_YOUT_L[0].<br>7: ACCEL_ZOUT_L[0]. |

## 10.18 TEMP\_CONFIG

| <b>Name:</b> TEMP_CONFIG<br><b>Address:</b> 83 (53h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
|--|------------------|--|------------------|-------------|--|--|----------|------------|---|--------|---|---|-------|-------|---|-------|-------|---|------|-------|---|------|-------|---|------|-------|---|-----|------------|---|--------|---|
| BIT  | NAME             | FUNCTION   |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 2:0  | TEMP_DLPCFG[2:0] | Low pass filter configuration for temperature sensor as shown in the table below: <table> <tr> <th>TEMP_DLPCFG&lt;2:0&gt;</th><th colspan="2">TEMP SENSOR</th></tr> <tr> <th></th><th>NBW (HZ)</th><th>RATE (KHZ)</th></tr> <tr> <td>0</td><td>7932.0</td><td>9</td></tr> <tr> <td>1</td><td>217.9</td><td>1.125</td></tr> <tr> <td>2</td><td>123.5</td><td>1.125</td></tr> <tr> <td>3</td><td>65.9</td><td>1.125</td></tr> <tr> <td>4</td><td>34.1</td><td>1.125</td></tr> <tr> <td>5</td><td>17.3</td><td>1.125</td></tr> <tr> <td>6</td><td>8.8</td><td>Rate (kHz)</td></tr> <tr> <td>7</td><td>7932.0</td><td>9</td></tr> </table> | TEMP_DLPCFG<2:0> | TEMP SENSOR |  |  | NBW (HZ) | RATE (KHZ) | 0 | 7932.0 | 9 | 1 | 217.9 | 1.125 | 2 | 123.5 | 1.125 | 3 | 65.9 | 1.125 | 4 | 34.1 | 1.125 | 5 | 17.3 | 1.125 | 6 | 8.8 | Rate (kHz) | 7 | 7932.0 | 9 |
| TEMP_DLPCFG<2:0>   | TEMP SENSOR      |  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
|  | NBW (HZ)         | RATE (KHZ)   |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 0  | 7932.0           | 9  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 1  | 217.9            | 1.125  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 2  | 123.5            | 1.125  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 3  | 65.9             | 1.125  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 4  | 34.1             | 1.125  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 5  | 17.3             | 1.125  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 6  | 8.8              | Rate (kHz)   |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |
| 7  | 7932.0           | 9  |                  |             |  |  |          |            |   |        |   |   |       |       |   |       |       |   |      |       |   |      |       |   |      |       |   |     |            |   |        |   |

## 10.19 MOD\_CTRL\_USR

| <b>Name:</b> MOD_CTRL_USR<br><b>Address:</b> 84 (54h)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x03 |               |  |
|---|---------------|--|
| BIT   | NAME          | FUNCTION   |
| 7:1   | -             | Reserved.  |
| 0   | REG_LP_DMP_EN | Enable turning on DMP in Low Power Accelerometer mode. |

## 10.20 REG\_BANK\_SEL

| <b>Name:</b> REG_BANK_SEL<br><b>Address:</b> 127 (7Fh)<br><b>Type:</b> USR2<br><b>Bank:</b> 2<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                |   |
|--|----------------|---|
| BIT  | NAME           | FUNCTION  |
| 7:6  | -              | Reserved.   |
| 5:4  | USER_BANK[1:0] | Use the following values in this bit-field to select a USER BANK.<br>0: Select USER BANK 0.<br>1: Select USER BANK 1.<br>2: Select USER BANK 2.<br>3: Select USER BANK 3. |
| 3:0  | -              | Reserved.   |

## 11 USR BANK 3 REGISTER MAP

This section describes the function and contents of the User Bank 3 Register Map within the ICM-20948.

**NOTE:** The device will come up in sleep mode upon power-up.

### 11.1 I2C\_MST\_ODR\_CONFIG

| <b>Name:</b> I2C_MST_ODR_CONFIG<br><b>Address:</b> 0 (00h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                         |  |
|--|-------------------------|--|
| BIT  | NAME                    | FUNCTION   |
| 7:4  | -                       | Reserved   |
| 3:0  | I2C_MST_ODR_CONFIG[3:0] | ODR configuration for external sensor when gyroscope and accelerometer are disabled. ODR is computed as follows:<br>$1.1 \text{ kHz} / (2^{((\text{odr\_config}[3:0]))})$<br>When gyroscope is enabled, all sensors (including I2C_MASTER) use the gyroscope ODR. If gyroscope is disabled, then all sensors (including I2C_MASTER) use the accelerometer ODR. |

### 11.2 I2C\_MST\_CTRL

| <b>Name:</b> I2C_MST_CTRL<br><b>Address:</b> 1 (01h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |   |
|--|------------------|---|
| BIT  | NAME             | FUNCTION  |
| 7  | MULT_MST_EN      | Enables multi-master capability. When disabled, clocking to the I2C_MST_IF can be disabled when not in use and the logic to detect lost arbitration is disabled.                      |
| 6:5  | -                | Reserved.   |
| 4  | I2C_MST_P_NSR    | This bit controls the I <sup>2</sup> C Master's transition from one slave read to the next slave read.<br>0 - There is a restart between reads.<br>1 - There is a stop between reads. |
| 3:0  | I2C_MST_CLK[3:0] | Sets I <sup>2</sup> C master clock frequency as shown in Table 23.  |

### 11.3 I2C\_MST\_DELAY\_CTRL

| <b>Name:</b> I2C_MST_DELAY_CTRL<br><b>Address:</b> 2 (02h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |   |
|--|-------------------|---|
| BIT  | NAME              | FUNCTION  |
| 7  | DELAY_ES_SHADOW   | Delays shadowing of external sensor data until all data is received.  |
| 6:5  | -                 | Reserved.   |
| 4  | I2C_SLV4_DELAY_EN | When enabled, slave 4 will only be accessed 1/(1+I2C_SLC4_DLY) samples as determined by I2C_MST_ODR_CONFIG. |
| 3  | I2C_SLV3_DELAY_EN | When enabled, slave 3 will only be accessed 1/(1+I2C_SLC4_DLY) samples as determined by I2C_MST_ODR_CONFIG. |
| 2  | I2C_SLV2_DELAY_EN | When enabled, slave 2 will only be accessed 1/(1+I2C_SLC4_DLY) samples as determined by I2C_MST_ODR_CONFIG. |
| 1  | I2C_SLV1_DELAY_EN | When enabled, slave 1 will only be accessed 1/(1+I2C_SLC4_DLY) samples as determined by I2C_MST_ODR_CONFIG. |
| 0  | I2C_SLV0_DELAY_EN | When enabled, slave 0 will only be accessed 1/(1+I2C_SLC4_DLY) samples as determined by I2C_MST_ODR_CONFIG. |

### 11.4 I2C\_SLV0\_ADDR

| <b>Name:</b> I2C_SLV0_ADDR<br><b>Address:</b> 3 (03h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|---|---------------|---|
| BIT   | NAME          | FUNCTION  |
| 7   | I2C_SLV0_RNW  | 1 – Transfer is a read.<br>0 – Transfer is a write. |
| 6:0   | I2C_ID_0[6:0] | Physical address of I <sup>2</sup> C slave 0.       |

### 11.5 I2C\_SLV0\_REG

| <b>Name:</b> I2C_SLV0_REG<br><b>Address:</b> 4 (04h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |  |
|--|-------------------|--|
| BIT  | NAME              | FUNCTION   |
| 7:0  | I2C_SLV0_REG[7:0] | I <sup>2</sup> C slave 0 register address from where to begin data transfer. |

## 11.6 I2C\_SLV0\_CTRL

| <b>Name:</b> I2C_SLV0_CTRL<br><b>Address:</b> 5 (05h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                    |  |
|---|--------------------|--|
| BIT   | NAME               | FUNCTION   |
| 7   | I2C_SLV0_EN        | 1 – Enable reading data from this slave at the sample rate and storing data at the first available EXT_SENS_DATA register, which is always EXT_SENS_DATA_00 for I <sup>2</sup> C slave 0.<br>0 – Function is disabled for this slave.  |
| 6   | I2C_SLV0_BYTE_SW   | 1 – Swap bytes when reading both the low and high byte of a word. Note there is nothing to swap after reading the first byte if I2C_SLV0_REG[0] = 1, or if the last byte read has a register address lsb = 0.<br>For example, if I2C_SLV0_REG = 0x1, and I2C_SLV0 LENG = 0x4:<br>1) The first byte read from address 0x1 will be stored at EXT_SENS_DATA_00,<br>2) the second and third bytes will be read and swapped, so the data read from address 0x2 will be stored at EXT_SENS_DATA_02, and the data read from address 0x3 will be stored at EXT_SENS_DATA_01,<br>3) The last byte read from address 0x4 will be stored at EXT_SENS_DATA_03.<br>0 – No swapping occurs; bytes are written in order read. |
| 5   | I2C_SLV0_REG_DIS   | When set, the transaction does not write a register value, it will only read data, or write data.  |
| 4   | I2C_SLV0_GRP       | External sensor data typically comes in as groups of two bytes. This bit is used to determine if the groups are from the slave's register address 0 and 1, 2 and 3, etc., or if the groups are address 1 and 2, 3 and 4, etc.<br>0 indicates slave register addresses 0 and 1 are grouped together (odd numbered register ends the group). 1 indicates slave register addresses 1 and 2 are grouped together (even numbered register ends the group). This allows byte swapping of registers that are grouped starting at any address.   |
| 3:0   | I2C_SLV0 LENG[3:0] | Number of bytes to be read from I <sup>2</sup> C slave 0.  |

## 11.7 I2C\_SLV0\_DO

| <b>Name:</b> I2C_SLV0_DO<br><b>Address:</b> 6 (06h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |  |
|---|------------------|--|
| BIT   | NAME             | FUNCTION                               |
| 7:0   | I2C_SLV0_DO[7:0] | Data out when slave 0 is set to write. |

## 11.8 I2C\_SLV1\_ADDR

| <b>Name:</b> I2C_SLV1_ADDR<br><b>Address:</b> 7 (07h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|---|---------------|---|
| BIT   | NAME          | FUNCTION  |
| 7   | I2C_SLV1_RNW  | 1 – Transfer is a read.<br>0 – Transfer is a write. |
| 6:0   | I2C_ID_1[6:0] | Physical address of I <sup>2</sup> C slave 1.       |

## 11.9 I2C\_SLV1\_REG

| <b>Name:</b> I2C_SLV1_REG<br><b>Address:</b> 8 (08h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |  |
|--|-------------------|--|
| BIT  | NAME              | FUNCTION   |
| 7:0  | I2C_SLV1_REG[7:0] | I <sup>2</sup> C slave 1 register address from where to begin data transfer. |

## 11.10 I2C\_SLV1\_CTRL

| <b>Name:</b> I2C_SLV1_CTRL<br><b>Address:</b> 9 (09h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                    |  |
|---|--------------------|--|
| BIT   | NAME               | FUNCTION   |
| 7   | I2C_SLV1_EN        | 1 – Enable reading data from this slave at the sample rate and storing data at the first available EXT_SENS_DATA register as determined by I2C_SLV0_EN and I2C_SLV0 LENG.<br>0 – Function is disabled for this slave.  |
| 6   | I2C_SLV1_BYTE_SW   | 1 – Swap bytes when reading both the low and high byte of a word. Note there is nothing to swap after reading the first byte if I2C_SLV1_REG[0] = 1, or if the last byte read has a register address lsb = 0.<br><br>For example, if I2C_SLV0_EN = 0x1, and I2C_SLV0 LENG = 0x3 (to show swap has to do with I2C slave address not EXT_SENS_DATA address), and if I2C_SLV1_REG = 0x1, and I2C_SLV1 LENG = 0x4:<br><br>1) The first byte read from address 0x1 will be stored at EXT_SENS_DATA_03 (slave 0's data will be in EXT_SENS_DATA_00, EXT_SENS_DATA_01, and EXT_SENS_DATA_02),<br>2) the second and third bytes will be read and swapped, so the data read from address 0x2 will be stored at EXT_SENS_DATA_04, and the data read from address 0x3 will be stored at EXT_SENS_DATA_05,<br>3) The last byte read from address 0x4 will be stored at EXT_SENS_DATA_06.<br><br>0 – No swapping occurs, bytes are written in order read. |
| 5   | I2C_SLV1_REG_DIS   | When set, the transaction does not write a register value, it will only read data, or write data.  |
| 4   | I2C_SLV1_GRP       | External sensor data typically comes in as groups of two bytes. This bit is used to determine if the groups are from the slave's register address 0 and 1, 2 and 3, etc., or if the groups are address 1 and 2, 3 and 4, etc.<br>0 indicates slave register addresses 0 and 1 are grouped together (odd numbered register ends the group). 1 indicates slave register addresses 1 and 2 are grouped together (even numbered register ends the group). This allows byte swapping of registers that are grouped starting at any address.   |
| 3:0   | I2C_SLV1_LENG[3:0] | Number of bytes to be read from I <sup>2</sup> C slave 1.  |

### 11.11 I2C\_SLV1\_DO

| <b>Name:</b> I2C_SLV1_DO<br><b>Address:</b> 10 (0Ah)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION                               |
| 7:0  | I2C_SLV1_DO[7:0] | Data out when slave 1 is set to write. |

### 11.12 I2C\_SLV2\_ADDR

| <b>Name:</b> I2C_SLV2_ADDR<br><b>Address:</b> 11 (0Bh)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|--|---------------|---|
| BIT  | NAME          | FUNCTION  |
| 7  | I2C_SLV2_RNW  | 1 – Transfer is a read.<br>0 – Transfer is a write. |
| 6:0  | I2C_ID_2[6:0] | Physical address of I <sup>2</sup> C slave 2.       |

### 11.13 I2C\_SLV2\_REG

| <b>Name:</b> I2C_SLV2_REG<br><b>Address:</b> 12 (0Ch)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |  |
|---|-------------------|--|
| BIT   | NAME              | FUNCTION   |
| 7:0   | I2C_SLV2_REG[7:0] | I <sup>2</sup> C slave 2 register address from where to begin data transfer. |



### 11.14 I2C\_SLV2\_CTRL

| <b>Name:</b> I2C_SLV2_CTRL<br><b>Address:</b> 13 (0Dh)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                    |  |
|--|--------------------|--|
| BIT  | NAME               | FUNCTION   |
| 7  | I2C_SLV2_EN        | 1 – Enable reading data from this slave at the sample rate and storing data at the first available EXT_SENS_DATA register as determined by I2C_SLV0_EN, I2C_SLV0 LENG, I2C_SLV1_EN and I2C_SLV1 LENG.<br>0 – Function is disabled for this slave.  |
| 6  | I2C_SLV2_BYTE_SW   | 1 – Swap bytes when reading both the low and high byte of a word. Note there is nothing to swap after reading the first byte if I2C_SLV2_REG[0] = 1, or if the last byte read has a register address lsb = 0.<br>See I2C_SLV1_CTRL for an example.<br>0 – No swapping occurs, bytes are written in order read.   |
| 5  | I2C_SLV2_REG_DIS   | When set, the transaction does not write a register value, it will only read data, or write data.  |
| 4  | I2C_SLV2_GRP       | External sensor data typically comes in as groups of two bytes. This bit is used to determine if the groups are from the slave's register address 0 and 1, 2 and 3, etc., or if the groups are address 1 and 2, 3 and 4, etc.<br>0 indicates slave register addresses 0 and 1 are grouped together (odd numbered register ends the group). 1 indicates slave register addresses 1 and 2 are grouped together (even numbered register ends the group). This allows byte swapping of registers that are grouped starting at any address. |
| 3:0  | I2C_SLV2 LENG[3:0] | Number of bytes to be read from I <sup>2</sup> C slave 2.  |

### 11.15 I2C\_SLV2\_DO

| <b>Name:</b> I2C_SLV2_DO<br><b>Address:</b> 14 (0Eh)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION                               |
| 7:0  | I2C_SLV2_DO[7:0] | Data out when slave 2 is set to write. |

### 11.16 I2C\_SLV3\_ADDR

| <b>Name:</b> I2C_SLV3_ADDR<br><b>Address:</b> 15 (0Fh)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|--|---------------|---|
| BIT  | NAME          | FUNCTION  |
| 7  | I2C_SLV3_RNW  | 1 – Transfer is a read.<br>0 – Transfer is a write. |
| 6:0  | I2C_ID_3[6:0] | Physical address of I <sup>2</sup> C slave 3.       |

### 11.17 I2C\_SLV3\_REG

| <b>Name:</b> I2C_SLV3_REG<br><b>Address:</b> 16 (10h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |  |
|---|-------------------|--|
| BIT   | NAME              | FUNCTION   |
| 7:0   | I2C_SLV3_REG[7:0] | I <sup>2</sup> C slave 3 register address from where to begin data transfer. |

### 11.18 I2C\_SLV3\_CTRL

| <b>Name:</b> I2C_SLV3_CTRL<br><b>Address:</b> 17 (11h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                    |  |
|--|--------------------|--|
| BIT  | NAME               | FUNCTION   |
| 7  | I2C_SLV3_EN        | 1 – Enable reading data from this slave at the sample rate and storing data at the first available EXT_SENS_DATA register as determined by I2C_SLV0_EN, I2C_SLV0 LENG, I2C_SLV1_EN, I2C_SLV1 LENG, I2C_SLV2_EN and I2C_SLV2 LENG.<br>0 – Function is disabled for this slave.  |
| 6  | I2C_SLV3_BYTE_SW   | 1 – Swap bytes when reading both the low and high byte of a word. Note there is nothing to swap after reading the first byte if I2C_SLV3_REG[0] = 1, or if the last byte read has a register address lsb = 0.<br>See I2C_SLV1_CTRL for an example.<br>0 – No swapping occurs, bytes are written in order read.   |
| 5  | I2C_SLV3_REG_DIS   | When set, the transaction does not write a register value, it will only read data, or write data.  |
| 4  | I2C_SLV3_GRP       | External sensor data typically comes in as groups of two bytes. This bit is used to determine if the groups are from the slave's register address 0 and 1, 2 and 3, etc., or if the groups are address 1 and 2, 3 and 4, etc.<br>0 indicates slave register addresses 0 and 1 are grouped together (odd numbered register ends the group). 1 indicates slave register addresses 1 and 2 are grouped together (even numbered register ends the group). This allows byte swapping of registers that are grouped starting at any address. |
| 3:0  | I2C_SLV3_LENG[3:0] | Number of bytes to be read from I <sup>2</sup> C slave 3.  |

### 11.19 I2C\_SLV3\_DO

| <b>Name:</b> I2C_SLV3_DO<br><b>Address:</b> 18 (12h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION                               |
| 7:0  | I2C_SLV3_DO[7:0] | Data out when slave 3 is set to write. |

## 11.20 I2C\_SLV4\_ADDR

| <b>Name:</b> I2C_SLV4_ADDR<br><b>Address:</b> 19 (13h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |               |   |
|--|---------------|---|
| BIT  | NAME          | FUNCTION  |
| 7  | I2C_SLV4_RNW  | 1 – Transfer is a read.<br>0 – Transfer is a write. |
| 6:0  | I2C_ID_4[6:0] | Physical address of I <sup>2</sup> C slave 4.       |

**NOTE:** The I<sup>2</sup>C Slave 4 interface can be used to perform only single byte read and write transactions.

## 11.21 I2C\_SLV4\_REG

| <b>Name:</b> I2C_SLV4_REG<br><b>Address:</b> 20 (14h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |  |
|---|-------------------|--|
| BIT   | NAME              | FUNCTION   |
| 7:0   | I2C_SLV4_REG[7:0] | I <sup>2</sup> C slave 4 register address from where to begin data transfer. |

## 11.22 I2C\_SLV4\_CTRL

| <b>Name:</b> I2C_SLV4_CTRL<br><b>Address:</b> 21 (15h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                   |   |
|--|-------------------|---|
| BIT  | NAME              | FUNCTION  |
| 7  | I2C_SLV4_EN       | 1 – Enable data transfer with this slave at the sample rate. If read command, store data in I2C_SLV4_DI register, if write command, write data stored in I2C_SLV4_DO register. Bit is cleared when a single transfer is complete. Be sure to write I2C_SLV4_DO first.<br>0 – Function is disabled for this slave. |
| 6  | I2C_SLV4_INT_EN   | 1 – Enables the completion of the I2C slave 4 data transfer to cause an interrupt.<br>0 – Completion of the I2C slave 4 data transfer will not cause an interrupt.  |
| 5  | I2C_SLV4_REG_DIS  | When set, the transaction does not write a register value, it will only read data, or write data.   |
| 4:0  | I2C_SLV4_DLY[4:0] | When enabled via the I2C_MST_DELAY_CTRL, those slaves will only be enabled every $1/(1+I2C\_SLV4\_DLY)$ samples as determined by I2C_MST_ODR_CONFIG.  |

## 11.23 I2C\_SLV4\_DO

| <b>Name:</b> I2C_SLV4_DO<br><b>Address:</b> 22 (16h)<br><b>Type:</b> USR3<br><b>Bank:</b> 3<br><b>Serial IF:</b> R/W<br><b>Reset Value:</b> 0x00 |                  |  |
|--|------------------|--|
| BIT  | NAME             | FUNCTION                               |
| 7:0  | I2C_SLV4_DO[7:0] | Data out when slave 4 is set to write. |

### 11.24 I2C\_SLV4\_DI

**Name:** I2C\_SLV4\_DI

**Address:** 23 (17h)

**Type:** USR3

**Bank:** 3

**Serial IF:** R

**Reset Value:** 0x00

| BIT | NAME             | FUNCTION                                 |
|-----|------------------|--|
| 7:0 | I2C_SLV4_DI[7:0] | Data read from I <sup>2</sup> C Slave 4. |

### 11.25 REG\_BANK\_SEL

**Name:** REG\_BANK\_SEL

**Address:** 127 (7Fh)

**Type:**

**Bank:** 3

**Serial IF:** R/W

**Reset Value:** 0x00

| BIT | NAME           | FUNCTION  |
|-----|----------------|---|
| 7:6 | -              | Reserved.   |
| 5:4 | USER_BANK[1:0] | Use the following values in this bit-field to select a USER BANK.<br>0: Select USER BANK 0.<br>1: Select USER BANK 1.<br>2: Select USER BANK 2.<br>3: Select USER BANK 3. |
| 3:0 | -              | Reserved.   |

## 12 REGISTER MAP FOR MAGNETOMETER

The register map for the ICM-20948's Magnetometer (AK09916) section is listed below.

| NAME  | ADDRESS | READ/WRITE  | DESCRIPTION      | BIT WIDTH | EXPLANATION      |
|-------|---------|-------------|------------------|-----------|------------------|
| WIA2  | 01H     | READ        | Device ID        | 8         |                  |
| ST1   | 10H     | READ        | Status 1         | 8         | Data status      |
| HXL   | 11H     | READ        | Measurement data | 8         | X-axis data      |
| HXH   | 12H     |             |                  | 8         |                  |
| HYL   | 13H     |             |                  | 8         | Y-axis data      |
| HYH   | 14H     |             |                  | 8         |                  |
| HZL   | 15H     |             |                  | 8         | Z-axis data      |
| HZH   | 16H     |             |                  | 8         |                  |
| ST2   | 18H     | READ        | Status 2         | 8         | Data status      |
| CNTL2 | 31H     | READ/ WRITE | Control 2        | 8         | Control Settings |
| CNTL3 | 32H     | READ/ WRITE | Control 3        | 8         | Control Settings |
| TS1   | 33H     | READ/ WRITE | Test             | 8         | DO NOT ACCESS    |
| TS2   | 34H     | READ/ WRITE | Test             | 8         | DO NOT ACCESS    |

**Table 20. Register Table for Magnetometer**

Addresses 00h to 18h, 30h to 32h are compliant with automatic increment function of serial interface respectively. In other modes, read data is not correct. When the address is in 00h to 18h, the address is incremented 00h → 01h → 02h → 03h → 10h → 11h →... → 18h, and the address goes back to 00h after 18h. When the address is in 30h to 32h, the address goes back to 30h after 32h.

### 12.1 REGISTER MAP DESCRIPTION

| ADDR                       | REGISTER NAME | D7   | D6    | D5    | D4    | D3    | D2    | D1    | D0    |
|----------------------------|---------------|------|-------|-------|-------|-------|-------|-------|-------|
| <b>READ-ONLY REGISTER</b>  |               |      |       |       |       |       |       |       |       |
| 01H                        | WIA2          | 0    | 0     | 0     | 0     | 1     | 0     | 0     | 1     |
| 10H                        | ST1           | 0    | 0     | 0     | 0     | 0     | 0     | DOR   | DRDY  |
| 11H                        | HXL           | HX7  | HX6   | HX5   | HX4   | HX3   | HX2   | HX1   | HX0   |
| 12H                        | HXH           | HX15 | HX14  | HX13  | HX12  | HX11  | HX10  | HX9   | HX8   |
| 13H                        | HYL           | HY7  | HY6   | HY5   | HY4   | HY3   | HY2   | HY1   | HY0   |
| 14H                        | HYH           | HY15 | HY14  | HY13  | HY12  | HY11  | HY10  | HY9   | HY8   |
| 15H                        | HZL           | HZ7  | HZ6   | HZ5   | HZ4   | HZ3   | HZ2   | HZ1   | HZ0   |
| 16H                        | HZH           | HZ15 | HZ14  | HZ13  | HZ12  | HZ11  | HZ10  | HZ9   | HZ8   |
| 18H                        | ST2           | 0    | RSV30 | RSV29 | RSV28 | HOFL  | 0     | 0     | 0     |
| <b>WRITE/READ REGISTER</b> |               |      |       |       |       |       |       |       |       |
| 31H                        | CNTL2         | 0    | 0     | 0     | MODE4 | MODE3 | MODE2 | MODE1 | MODE0 |
| 32H                        | CNTL3         | 0    | 0     | 0     | 0     | 0     | 0     | 0     | SRST  |
| 33H                        | TS1           | -    | -     | -     | -     | -     | -     | -     | -     |
| 34H                        | TS2           | -    | -     | -     | -     | -     | -     | -     | -     |

**Table 21. Register Map for Magnetometer**

When VDD is turned ON, POR function works and all registers of AK09916 are initialized.

TS1 and TS2 are test registers for shipment test. Do not access these registers.

## 13 DETAILED DESCRIPTIONS FOR MAGNETOMETER REGISTERS

This section details each register within the ICM-20948 Magnetometer section.

### 13.1 WIA: DEVICE ID

| ADDR               | REGISTER NAME | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|--------------------|---------------|----|----|----|----|----|----|----|----|
| READ-ONLY REGISTER |               |    |    |    |    |    |    |    |    |
| 01H                | WIA           | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 1  |

Device ID of AK09916. It is described in one byte and fixed value.

09H: fixed

### 13.2 ST1: STATUS 1

| ADDR               | REGISTER NAME | D7 | D6 | D5 | D4 | D3 | D2 | D1  | D0   |
|--------------------|---------------|----|----|----|----|----|----|-----|------|
| READ-ONLY REGISTER |               |    |    |    |    |    |    |     |      |
| 10H                | ST1           | 0  | 0  | 0  | 0  | 0  | 0  | DOR | DRDY |
|                    | Reset         | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0    |

DRDY: Data Ready

“0”: Normal

“1”: Data is ready

DRDY bit turns to “1” when data is ready in Single measurement mode, Continuous measurement mode 1, 2, 3, 4 or Self-test mode. It returns to “0” when any one of ST2 register or measurement data register (HXL to TMPS) is read.

DOR: Data Overrun

“0”: Normal

“1”: Data overrun

DOR bit turns to “1” when data has been skipped in Continuous measurement mode 1, 2, 3, 4. It returns to “0” when any one of ST2 register or measurement data register (HXL to TMPS) is read.

### 13.3 HXL TO HZH: MEASUREMENT DATA

| ADDR               | REGISTER NAME | D7   | D6   | D5   | D4   | D3   | D2   | D1  | D0  |
|--------------------|---------------|------|------|------|------|------|------|-----|-----|
| READ-ONLY REGISTER |               |      |      |      |      |      |      |     |     |
| 11H                | HXL           | HX7  | HX6  | HX5  | HX4  | HX3  | HX2  | HX1 | HX0 |
| 12H                | HXH           | HX15 | HX14 | HX13 | HX12 | HX11 | HX10 | HX9 | HX8 |
| 13H                | HYL           | HY7  | HY6  | HY5  | HY4  | HY3  | HY2  | HY1 | HY0 |
| 14H                | HYH           | HY15 | HY14 | HY13 | HY12 | HY11 | HY10 | HY9 | HY8 |
| 15H                | HZL           | HZ7  | HZ6  | HZ5  | HZ4  | HZ3  | HZ2  | HZ1 | HZ0 |
| 16H                | HZH           | HZ15 | HZ14 | HZ13 | HZ12 | HZ11 | HZ10 | HZ9 | HZ8 |
|                    | Reset         | 0    | 0    | 0    | 0    | 0    | 0    | 0   | 0   |

Measurement data of magnetic sensor X-axis/Y-axis/Z-axis

HXL[7:0]: X-axis measurement data lower 8bit

HXH[15:8]: X-axis measurement data higher 8bit

HYL[7:0]: Y-axis measurement data lower 8bit

HYH[15:8]: Y-axis measurement data higher 8bit

HZL[7:0]: Z-axis measurement data lower 8bit

HZH[15:8]: Z-axis measurement data higher 8bit

Measurement data is stored in two's complement and Little Endian format. Measurement range of each axis is from -32752 to 32752 in 16-bit output.

| MEASUREMENT DATA (EACH AXIS) [15:0] |      |         | MAGNETIC FLUX DENSITY [ $\mu$ T] |
|-------------------------------------|------|---------|----------------------------------|
| TWO'S COMPLEMENT                    | HEX  | DECIMAL |                                  |
| 0111 1111 1111 0000                 | 7FF0 | 32752   | 4912(max.)                       |
|                                     |      |         |                                  |
| 0000 0000 0000 0001                 | 0001 | 1       | 0.15                             |
| 0000 0000 0000 0000                 | 0000 | 0       | 0                                |
| 1111 1111 1111 1111                 | FFFF | -1      | -0.15                            |
|                                     |      |         |                                  |
| 1000 0000 0001 0000                 | 8010 | -32752  | -4912(min.)                      |

**Table 22. Magnetometer Measurement Data Format**

### 13.4 ST2: STATUS 2

| ADDR               | REGISTER NAME | D7 | D6    | D5    | D4    | D3   | D2 | D1 | D0 |
|--------------------|---------------|----|-------|-------|-------|------|----|----|----|
| READ-ONLY REGISTER |               |    |       |       |       |      |    |    |    |
| 18H                | ST2           | 0  | RSV30 | RSV29 | RSV28 | HOFL | 0  | 0  | 0  |
|                    | Reset         | 0  | 0     | 0     | 0     | 0    | 0  | 0  | 0  |

ST2[6:4] bits: Reserved register for AKM.

HOFL: Magnetic sensor overflow

"0": Normal

"1": Magnetic sensor overflow occurred

In Single measurement mode, Continuous measurement mode 1, 2, 3, 4, and Self-test mode, magnetic sensor may overflow even though measurement data register is not saturated. In this case, measurement data is not correct and HOFL bit turns to "1". When measurement data register is updated, HOFL bit is updated.

ST2 register has a role as data reading end register, also. When any of measurement data register (HXL to TMPS) is read in Continuous measurement mode 1, 2, 3, 4, it means data reading start and taken as data reading until ST2 register is read. Therefore, when any of measurement data is read, be sure to read ST2 register at the end.

### 13.5 CNTL2: CONTROL 2

| ADDR                | REGISTER NAME | D7 | D6 | D5 | D4    | D3    | D2    | D1    | D0    |
|---------------------|---------------|----|----|----|-------|-------|-------|-------|-------|
| READ/WRITE REGISTER |               |    |    |    |       |       |       |       |       |
| 31H                 | CNTL2         | 0  | 0  | 0  | MPDE4 | MODE3 | MODE2 | MODE1 | MODE0 |
|                     | Reset         | 0  | 0  | 0  | 0     | 0     | 0     | 0     | 0     |

MODE[4:0] bits: Operation mode setting

"00000": Power-down mode

"00001": Single measurement mode

"00010": Continuous measurement mode 1

"00100": Continuous measurement mode 2

“00110”: Continuous measurement mode 3

“01000”: Continuous measurement mode 4

“10000”: Self-test mode

Other code settings are prohibited

When each mode is set, AK09916 transits to the set mode.

### 13.6 CNTL3: CONTROL 3

| ADDR                | REGISTER NAME | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0   |
|---------------------|---------------|----|----|----|----|----|----|----|------|
| READ/WRITE REGISTER |               |    |    |    |    |    |    |    |      |
| 32H                 | CNTL3         | 0  | 0  | 0  | 0  | 0  | 0  | 0  | SRST |
| Reset               |               | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0    |

SRST: Soft reset

"0": Normal

"1": Reset

When “1” is set, all registers are initialized. After reset, SRST bit turns to “0” automatically.

### 13.7 TS1, TS2: TEST 1, 2

| ADDR                | REGISTER NAME | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------------|---------------|----|----|----|----|----|----|----|----|
| READ/WRITE REGISTER |               |    |    |    |    |    |    |    |    |
| 33H                 | TS1           | -  | -  | -  | -  | -  | -  | -  | -  |
| 34H                 | TS2           | -  | -  | -  | -  | -  | -  | -  | -  |
| Reset               |               | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

TS1 and TS2 registers are test registers for shipment test. Do not use these registers.



## 14 USE NOTES

### 14.1 GYROSCOPE MODE TRANSITION

When gyroscope is transitioning from low-power to low-noise mode, several unsettled output samples will be observed at the gyroscope output due to filter switching and settling. The number of unsettled gyroscope output samples depends on the filter and ODR settings.

### 14.2 POWER MANAGEMENT 1 REGISTER SETTING

CLKSEL[2:0] has to be set to 001 to achieve the datasheet performance.

### 14.3 DMP MEMORY ACCESS

Reading/writing DMP memory and FIFO through I<sup>2</sup>C in a multithreaded environment can cause wrong data being read. To avoid the issue, one may use SPI instead of I<sup>2</sup>C, or use I<sup>2</sup>C with mutexes.

### 14.4 TIME BASE CORRECTION

The system clock frequency at room temperature in gyroscope mode and 6-Axis mode varies from part to part, and the clock rates specified in datasheet are the nominal values. The percentage of frequency deviation from the nominal values for each part is logged in register TIMEBASE\_CORRECTION\_PLL, and the range of the code is  $\pm 10\%$  with each LSB representing a step of 0.079%. For example, if on one part TIMEBASE\_CORRECTION\_PLL = 0x0C = d'12, it means the clock frequency in gyroscope mode and 6-Axis mode is  $\sim 0.94\%$  faster than the nominal value.

When operating in accelerometer-only mode, the system clock frequency at room temperature is the nominal frequency over parts, and it is independent of the value stored in TIMEBASE\_CORRECTION\_PLL register.

### 14.5 I<sup>2</sup>C MASTER CLOCK FREQUENCY

I<sup>2</sup>C master clock frequency can be set by register I2C\_MST\_CLK as shown in Table 23. Due to temperature variation and part to part variation of system clock frequency in different power modes, I2C\_MST\_CLK should be set such that in all conditions the clock frequency will not exceed what a slave device can support. To achieve a targeted clock frequency of 400 kHz, MAX, it is recommended to set I2C\_MST\_CLK = 7 (345.6 kHz / 46.67% duty cycle).

| I2C_MST_CLK | NOMINAL CLK<br>FREQUENCY [KHZ] | DUTY CYCLE |
|-------------|--------------------------------|------------|
| 0           | 370.29                         | 50.00%     |
| 1           | -                              | -          |
| 2           | 370.29                         | 50.00%     |
| 3           | 432.00                         | 50.00%     |
| 4           | 370.29                         | 42.86%     |
| 5           | 370.29                         | 50.00%     |
| 6           | 345.60                         | 40.00%     |
| 7           | 345.60                         | 46.67%     |
| 8           | 304.94                         | 47.06%     |
| 9           | 432.00                         | 50.00%     |
| 10          | 432.00                         | 41.67%     |
| 11          | 432.00                         | 41.67%     |
| 12          | 471.27                         | 45.45%     |
| 13          | 432.00                         | 50.00%     |

| I2C_MST_CLK | NOMINAL CLK<br>FREQUENCY [KHZ] | DUTY CYCLE |
|-------------|--------------------------------|------------|
| 14          | 345.60                         | 46.67%     |
| 15          | 345.60                         | 46.67%     |

**Table 23. I<sup>2</sup>C Master Clock Frequency**

## 14.6 CLOCKING

The internal system clock sources include: (1) an internal relaxation oscillator, and (2) a PLL with MEMS gyroscope oscillator as the reference clock. With the recommended clock selection setting (CLKSEL = 1), the best clock source for optimum sensor performance and power consumption will be automatically selected based on the power mode. Specifically, the internal relaxation oscillator will be selected when operating in accelerometer only mode, while the PLL will be selected whenever gyroscope is on, which includes gyroscope and 6-axis modes.

As clock accuracy is critical to the preciseness of distance and angle calculations performed by DMP, it should be noted that the internal relaxation oscillator and PLL show different performances in some aspects. The internal relaxation oscillator is trimmed to have a consistent operating frequency at room temperature, while the PLL clock frequency varies from part to part. The PLL frequency deviation from the nominal value in percentage is captured in register TIMEBASE\_CORRECTION\_PLL, and users can factor it in during distance and angle calculations to not sacrifice accuracy. Other than that, PLL has better frequency stability and lower frequency variation over temperature than the internal relaxation oscillator.

## 14.7 LP\_EN BIT-FIELD USAGE

The LP\_EN bit-field (User Bank 0, PWR\_MGMT\_1 register, bit [5] helps to reduce the digital current. The recommended setting for this bit-field is 1 to achieve the lowest possible current. However, when LP\_EN is set to 1, user may not be able to write to the following registers. If it is desired to write to registers in this list, it is recommended to first set LP\_EN=0, write the desired register(s), then set LP\_EN=1 again:

- USER BANK 0: All registers except LP\_CONFIG, PWR\_MGMT\_1, PWR\_MGMT\_2, INT\_PIN\_CFG, INT\_ENABLE, FIFO\_COUNTH, FIFO\_COUNTL, FIFO\_R\_W, FIFO\_CFG, REG\_BANK\_SEL
- USER BANK 1: All registers except REG\_BANK\_SEL
- USER BANK 2: All registers except REG\_BANK\_SEL
- USER BANK 3: All registers except REG\_BANK\_SEL

## 14.8 REGISTER ACCESS USING SPI INTERFACE

Using the SPI interface, when the AP/user disables the gyroscope sensor (User Bank 0, PWR\_MGMT\_2 register, bits [2:0]=111) as part of a sequence of register read or write commands, the AP/user will be required to subsequently wait 22  $\mu$ s prior to any of the following operations:

(1) Writing to any of the following registers:

- USER BANK 0: All registers except LP\_CONFIG, PWR\_MGMT\_1, PWR\_MGMT\_2, INT\_PIN\_CFG, INT\_ENABLE, FIFO\_COUNTH, FIFO\_COUNTL, FIFO\_R\_W, FIFO\_CFG, REG\_BANK\_SEL
- USER BANK 1: All registers except REG\_BANK\_SEL
- USER BANK 2: All registers except REG\_BANK\_SEL
- USER BANK 3: All registers except REG\_BANK\_SEL

(2) Reading data from FIFO

(3) Reading from memory

## 15 ORIENTATION OF AXES

Figure 12 and Figure 13 show the orientation of the axes of sensitivity and the polarity of rotation. Note the pin 1 identifier (•) in the figures.

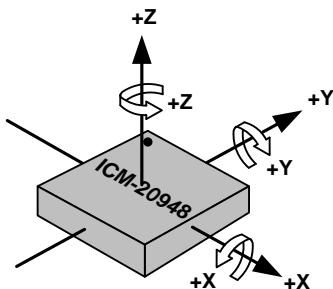


Figure 12. Orientation of Axes of Sensitivity and Polarity of Rotation

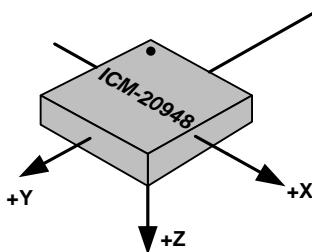


Figure 13. Orientation of Axes of Sensitivity for Magnetometer

## 16 PACKAGE DIMENSIONS

This section provides package dimensions for the device. Information for the 24 Lead QFN 3.0x3.0x0.9 package is in Figure 14 and Table 24

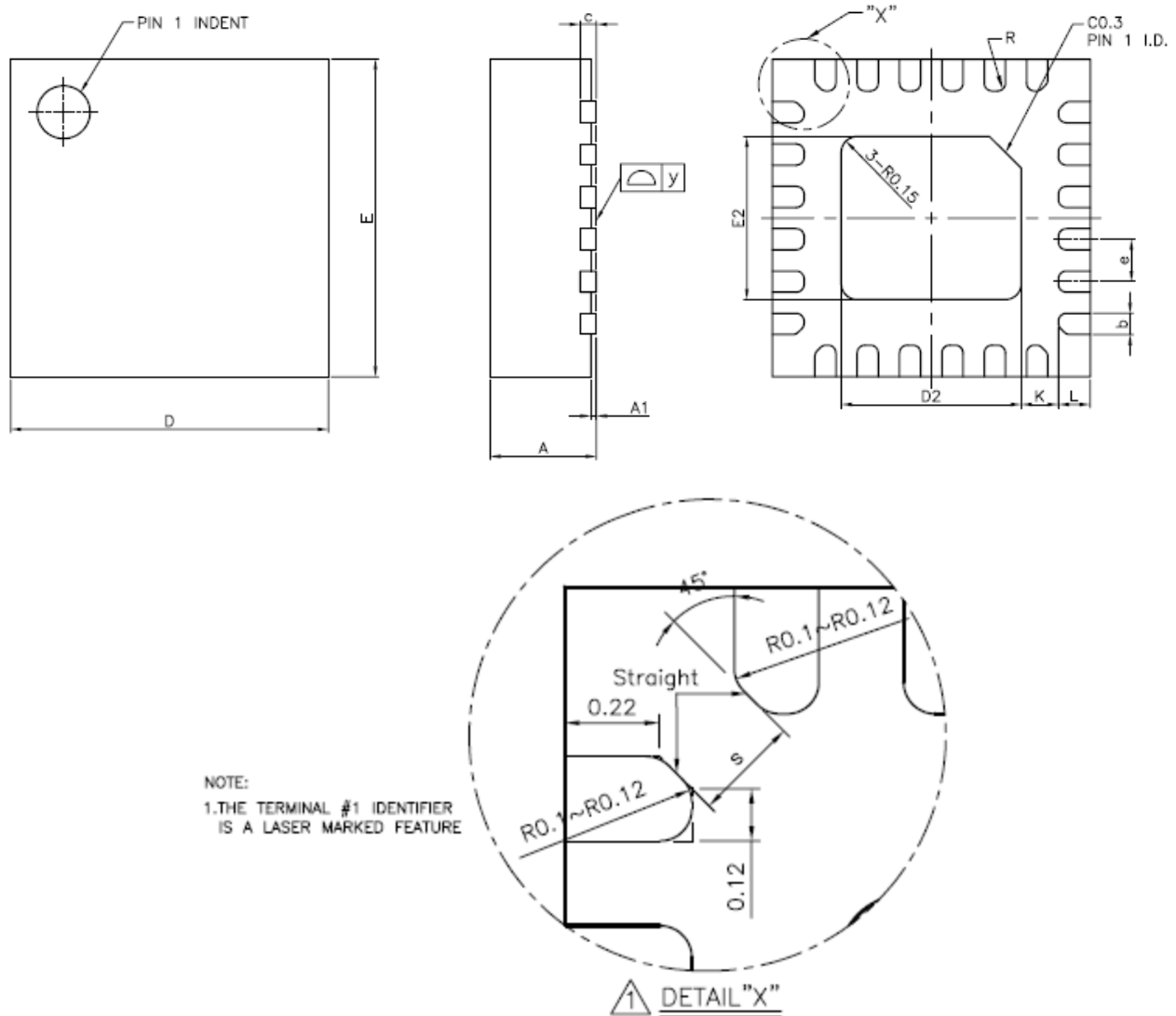


Figure 14. Package Dimensions

| SYMBOLS | DIMENSIONS IN MILLIMETERS |           |       |
|---------|---------------------------|-----------|-------|
|         | MIN.                      | NOM.      | MAX.  |
| A       | 0.95                      | 1.00      | 1.05  |
| A1      | 0.00                      | 0.02      | 0.05  |
| b       | 0.15                      | 0.20      | 0.25  |
| c       | ---                       | 0.15 REF. | ---   |
| D       | 2.90                      | 3.00      | 3.10  |
| D2      | 1.65                      | 1.70      | 1.75  |
| E       | 2.90                      | 3.00      | 3.10  |
| E2      | 1.49                      | 1.54      | 1.59  |
| e       | ---                       | 0.40      | ---   |
| K       | ---                       | 0.35 REF. | ---   |
| L       | 0.25                      | 0.30      | 0.35  |
| R       | 0.075                     | REF.      | ---   |
| s       | ---                       | 0.25 REF. | ---   |
| y       | 0.00                      | ---       | 0.075 |

**Table 24. Package Dimensions**

## 17 PART NUMBER PART MARKINGS

The part number part markings for ICM-20948 devices are summarized below:

| PART NUMBER | PART NUMBER PART MARKING |
|-------------|--------------------------|
| ICM-20948   | I2948                    |

Table 25. Part Number Part Markings

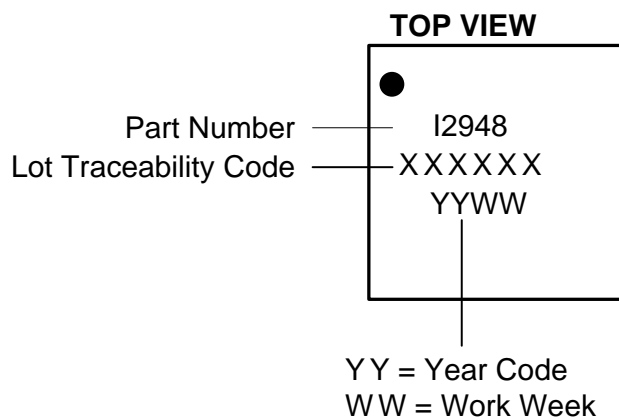


Figure 15. Part Number Part Markings

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## **18 REFERENCES**

Please refer to “InvenSense MEMS Handling Application Note (AN-IVS-0002A-00)” for the following information:

- Manufacturing Recommendations
  - Assembly Guidelines and Recommendations
  - PCB Design Guidelines and Recommendations
  - MEMS Handling Instructions
  - ESD Considerations
  - Reflow Specification
  - Storage Specifications
  - Package Marking Specification
  - Tape & Reel Specification
  - Reel & Pizza Box Label
  - Packaging
  - Representative Shipping Carton Label
- Compliance
  - Environmental Compliance
  - DRC Compliance
  - Compliance Declaration Disclaimer

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**19 DOCUMENT INFORMATION****19.1 REVISION HISTORY**

| REVISION DATE | REVISION | DESCRIPTION           |
|---------------|----------|-----------------------|
| 12/07/2016    | 1.0      | Initial Release       |
| 1/17/2017     | 1.1      | Formatting fix        |
| 04/06/2017    | 1.2      | Updated Section 4     |
| 06/02/2017    | 1.3      | Updated Sections 3, 4 |



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