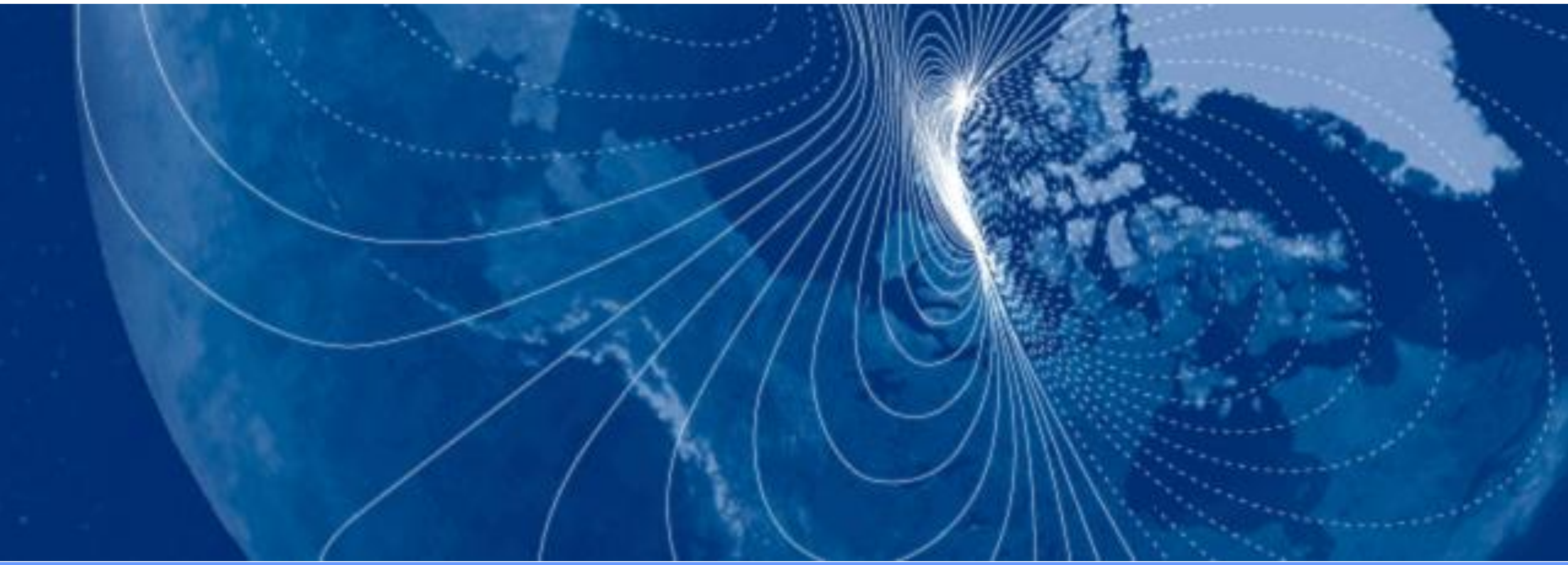

User Manual

RM3000-f Evaluation Board

3-Axis Geomagnetic Sensor Module

PNI SENSOR CORPORATION

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1 Copyright & Warranty Information

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2 Introduction

Thank you for purchasing PNI Sensor Corporation's RM3000-f Evaluation Board (pn 13094). The RM3000-f Evaluation Board is a plug-and-play version of PNI's RM3000-f Geomagnetic Sensor, principally intended for quickly evaluating and prototyping PNI's geomagnetic sensor technology. The primary components of the RM3000-f Evaluation Board are two Sen-XY-f geomagnetic sensor coils, one Sen-Z-f geomagnetic sensor coil, and PNI's 3D MagIC ASIC controller. It also incorporates resistors, capacitors, and connectors, all mounted on a PCB, to provide a complete magnetic field sensing module. The SPI interface allows easy access to the module's measurement parameters and resulting field measurement data.

PNI's magneto-inductive sensor technology provides high resolution, low power consumption, large signal noise immunity, a large dynamic range, and high sampling rates. Measurements are stable over temperature and inherently free from offset drift. The RM3000-f Evaluation Board features software-configurable resolution, sample rate and field measurement range, including the ability to operate one, two, or all three PNI sensor coils. These advantages make PNI's RM3000-f Evaluation Board not only the choice for prototyping high volume solutions, but also for lower volume applications that require a complete solution.

3 Specifications

3.1 RM3000-f Evaluation Board Characteristics

Table 3-1: Absolute Maximum Ratings

Parameter	Minimum	Maximum	Units
Analog/Digital DC Supply Voltage (AV_{DD} & DV_{DD})	-0.3	+3.7	VDC
Input Pin Voltage	-0.3	V_{DD} + 0.3	VDC
Input Pin Current @ 25C	-10.0	+10.0	mA
Storage Temperature	-40°	+85°	C

CAUTION:

Stresses beyond those listed above may cause permanent damage to the device. These are stress ratings only. Operation of the device at these or other conditions beyond those indicated in the operational sections of the specifications is not implied.

Table 3-2: Operating Characteristics[1]

Parameter	Min	Typical	Max	Units
Field measurement range[2]	-800		+800	µT
Gain @ 200 Cycle Counts[3]		45		counts/µT
Noise @ 200 Cycle Counts [3]		30		nT
Maximum Sample Rate per Axis @ 200 Cycle Counts[4]		475		Hz
Linearity - best fit over ±200 µT		0.6	1.0	% of ±200 µT
DC Supply Voltage	1.6	3.3	3.6	VDC
Supply Voltage Ripple			0.05	V_{PP}
Average Current per Axis @ 35 Hz and 200 Cycle Counts[5]		0.25		mA
Idle Mode Current			1	µA
Leakage Current			100	nA
Operating Temperature	-40		+85	C

Notes:

1) Specifications subject to change.
2) Field measurement range is defined as the monotonic region of the output characteristic curve.
3) Resolution is the inverse of gain, but system noise can limit the useable resolution of the RM3000-f Evaluation Board. Above ~200 cycle counts there are diminishing returns on useable resolution due to system noise.

4) The maximum sample rate and the gain are inversely related, such that higher sample rates can be obtained by reducing the number of cycle counts, but this also results in reduced gain and resolution. Also see Figure 3-1 and Figure 3-2.
5) Operating at greater cycle counts will increase power consumption but generally not provide any benefit in useable resolution due to system noise. 35 Hz single-axis output rate represents ~12 Hz output rate for all 3 axes for the RM3000-f Evaluation Board. Also see Figure 3-3.

3.2 Typical Operating Performance

The plots below are representative of performance as a function of the number of cycle counts. The number of cycle counts is determined by the user, as explained in Section 5.1. The maximum number of cycle counts is 65.5k. But there's rarely a reason to operate beyond 250 cycle counts, as explained in the following paragraph, and for this reason the plots only go to 250 cycle counts.

System noise limits the useable resolution of the RM3000-f Evaluation Board above ~200 cycle counts. Above 200 cycle counts there are diminishing returns on useable resolution, as greater cycle counts result in more time and power consumed per measurement with little improvement in useable resolution. For this reason, the plots only go to 250 cycle counts.

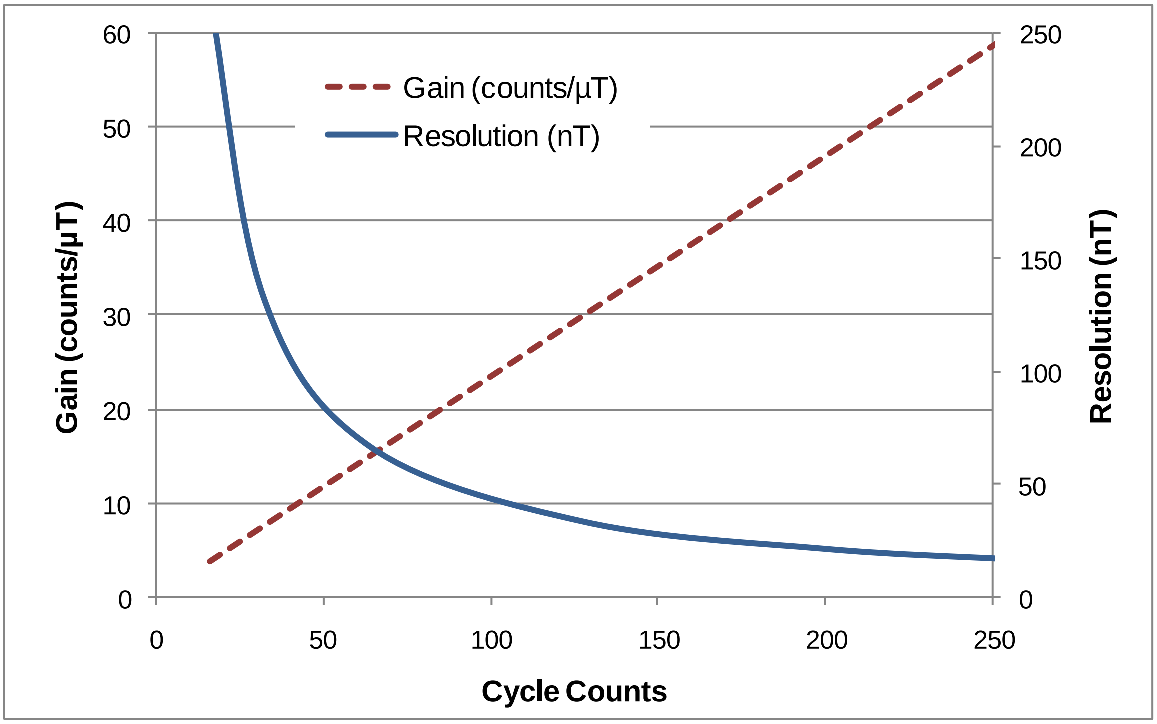

Figure 3-1: Gain & Resolution vs. Cycle Counts

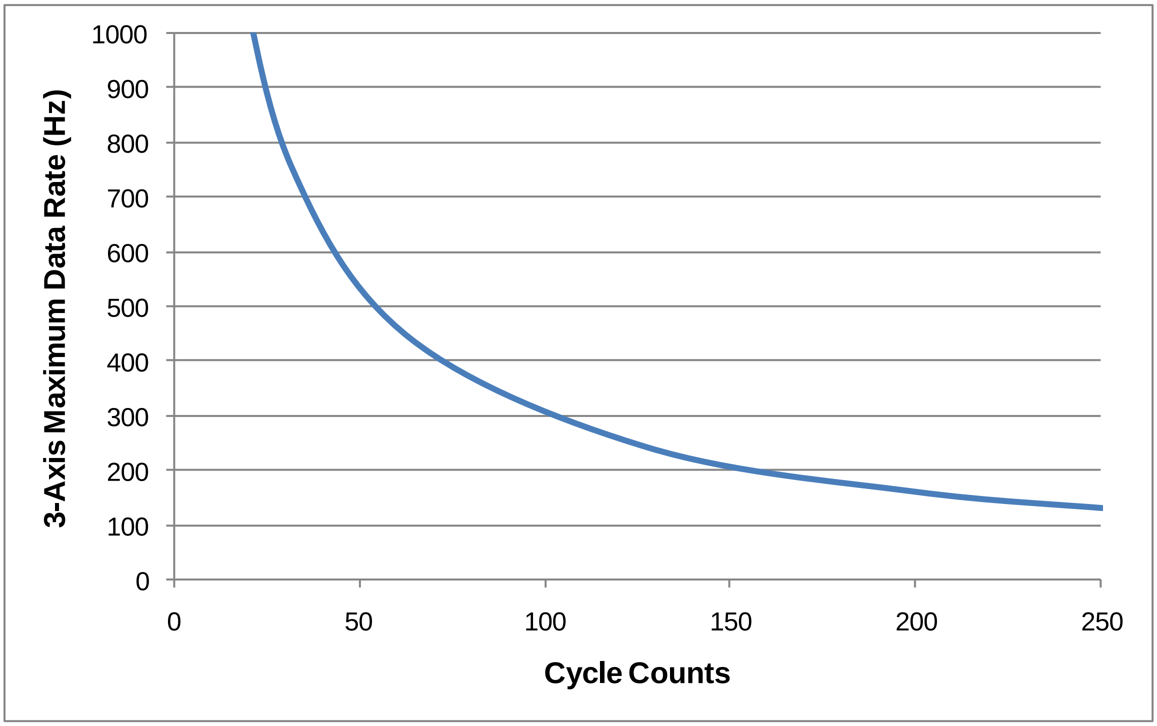

Figure 3-2: 3-Axis Maximum Sample Rate vs. Cycle Counts

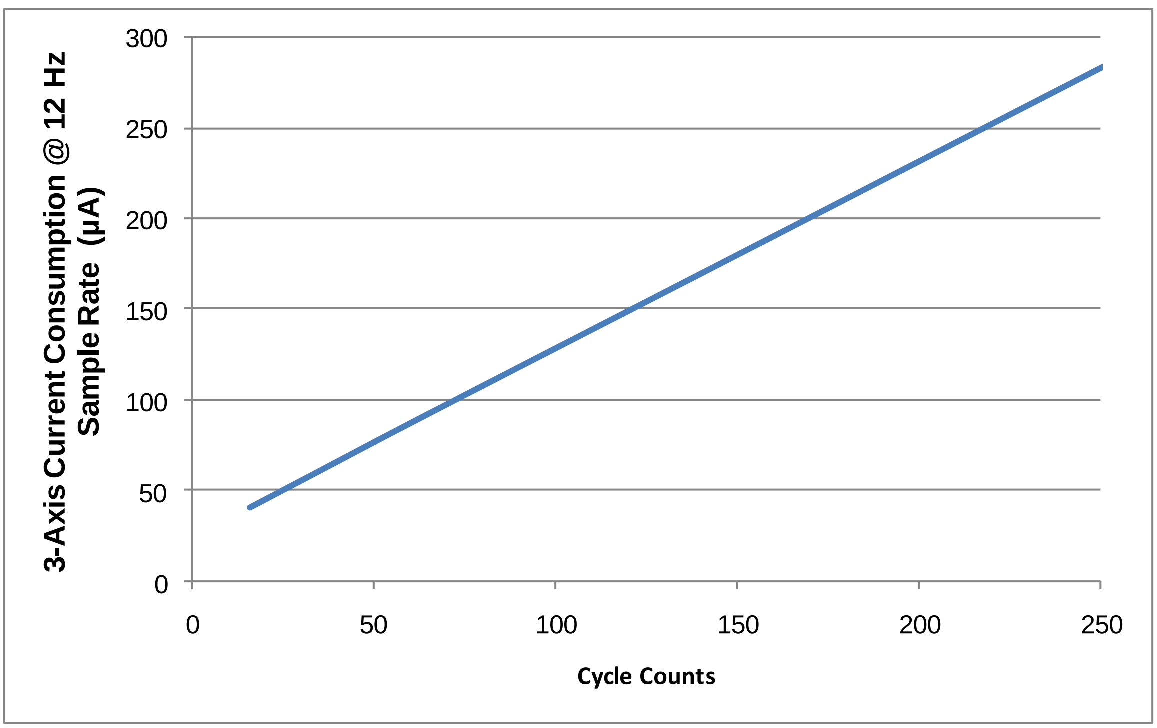

Figure 3-3: Current Consumption vs. Cycle Counts

3.3 Dimensions

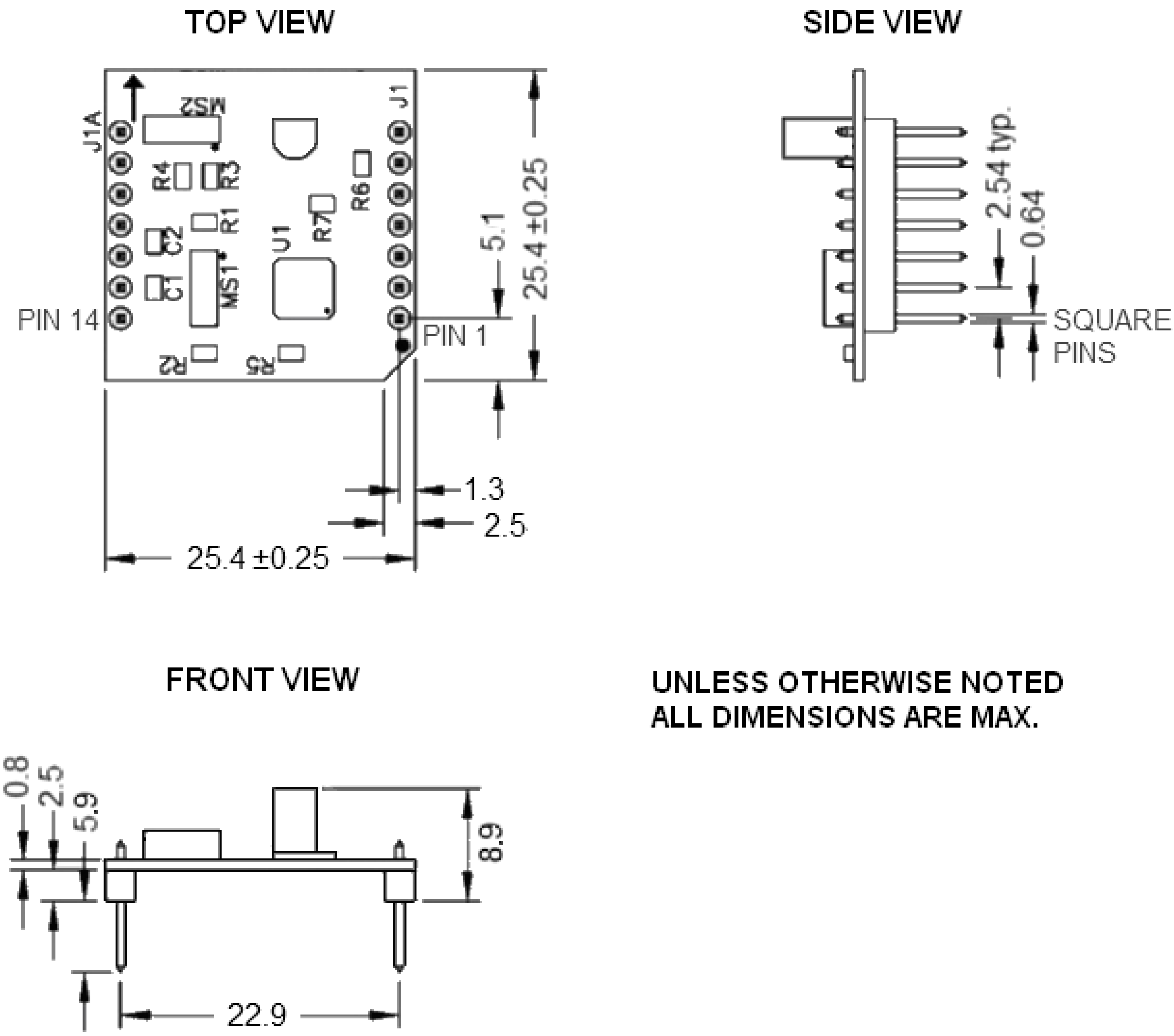

Figure 3-4: Mechanical Drawing

4 RM3000-f Evaluation Board Overview & Set-Up

4.1 PCB Orientation and Output Polarities

The arrow printed on the RM3000-f Evaluation Board indicates the reference direction for the module. The sensors are arranged in a north-east-down (NED) coordinate system, and the arrow is parallel to the x-axis sensor. When the module is pointing directly magnetic south the x-axis reading will be maximized and the y-axis will be zero. Likewise, when the module is pointing west the y-axis reading will be maximized and the x-axis reading will be zero. The z-axis reading will depend on the dip angle at the given location. At the geo-magnetic equator, where Earth's magnetic field is horizontal, the z-axis reading will be zero when flat.

4.2 RM3000-f Evaluation Board Pinout

The RM3000-f Evaluation Board's pin assignments are given in Table 4-1. Pin numbers run counterclockwise (when looking from the top), starting at the Pin 1 designator as shown in Figure 3-4**Error! Reference source not found.**. Since the board's labeling differs slightly from standard SPI terminology, the standard SPI term is also given. This manual will proceed with standard SPI terminology.

Table 4-1: RM3000-f Evaluation Board Pin Assignments

Pin#	RM3000-f Eval Board Pin Name	SPI Standard Pin Name	Description
1	SCK	SCLK	SPI interface - Serial clock input
2	SO	MISO	SPI interface – Master Input, Slave Output
3	SI	MOSI	SPI interface – Master Output, Slave Input
4	SSN	SSN	SPI interface – Active low to select port
5	DRDY	DRDY	Data ready command
6	CLR	CLEAR	Clear Command Register
7	GND	GND	Ground
8	NC	NC	Do not connect
9	NC	NC	Do not connect
10	NC	NC	Do not connect
11	NC	NC	Do not connect
12	Vdd	V_{DD}	DC Supply voltage
13	NC	NC	Do not connect
14	GND	GND	Ground

SCLK (SPI Serial Clock Input)

SCLK is a SPI input used to synchronize the data sent in and out through the MISO and MOSI pins. SCLK is generated by the customer-supplied master device and should be 1 MHz or less. One byte of data is exchanged over eight clock cycles. Data is captured by the master device on the rising edge of SCLK. Data is shifted out and presented to the 3D MagIC on the MOSI pin on the falling edge of SCLK, except for the first bit (MSB) which must be present before the first rising edge of SCLK.

SSN (SPI Slave Select)

This signal sets the 3D MagIC as the operating slave device on the SPI bus. The SSN pin must be LOW prior to data transfer in either direction, and must stay LOW during the entire transfer.

The SSN pin must transition from HIGH to LOW prior to initiating a multi-axis measurement (MAM) command and prior to reading or writing to the Cycle Count Register or Clock Divide Register. It must stay LOW for the remainder of the operation.

After communication between the 3D MagIC and master device is finished, the SPI bus can be freed up (SSN pin set HIGH) to communicate with other slave devices while the 3D MagIC takes a measurement or is idle.

MISO (SPI Serial Out)

MISO is a SPI output that sends data from the 3D MagIC to the master device. Data is transferred most significant bit first and is captured by the master device on the rising edge of SCLK. The MISO pin is placed in a high impedance state if the 3D MagIC is not selected (i.e. if SSN=1).

MOSI (SPI Serial In)

MOSI is a SPI input that provides data from the master device to the 3D MagIC. Data is transferred most significant bit first. Data must be presented at least 50 ns before the rising edge of SCLK, and remain valid for 50 ns after the edge. New data typically is presented to the MOSI pin on the falling edge of SCLK.

DRDY (Data Ready)

DRDY is used to ensure data is read from the 3D MagIC only when it is available. After initiating a sensor measurement, DRDY will go HIGH when the measurement is complete. This signals the host that data is ready to be read. The DRDY pin should be set LOW prior to initiating a measurement. This is done automatically in Standard Mode and by toggling the CLEAR pin in Legacy Mode.

Note: *If a new command sequence is started before the previous measurement has completed (before DRDY goes HIGH), the previous command will be overwritten. This will also stop the measurement cycle. If you try to send a new command during the readout phase, after DRDY goes HIGH, the command will be ignored until all 16 bits have been clocked our or the CLEAR pin is set HIGH (then LOW again).*

CLEAR (Clear Command Register)

To initiate a clear command in Legacy Mode, the CLEAR pin must be toggled LOW-HIGH-LOW. CLEAR is usually LOW. CLEAR will reset the DRDY pin to LOW. CLEAR can be used to stop any sensor measurement in progress. CLEAR has no effect on the SPI register state.

Note: *The CLEAR pin is similar to the RESET pin on PNI’s legacy ASIC. However in Standard Mode the 3D MagIC automatically resets the DRDY line, so it is not necessary to use the CLEAR pin when operating in Standard Mode.*

Vdd (Supply Voltage)

The recommend supply voltage, Vdd, and associated ripple are defined in Table 3-2, and the maximum voltage is given in Table 3-1.

GND (Ground Pins)

The two ground pins may be tied to a clean common ground plane or they may have their own ground planes. The pins should be within 0.1 V of each other.

4.3 SPI Interface Operation

When implementing an SPI port, whether a dedicated hardware peripheral port or a software-implemented port using general purpose I/O (also known as *Bit-Banging*), the timing parameters (defined below in Figure 4-1 and specified in Table 4-2) must be met to ensure reliable communications. The SPI clock (SCLK) should run at 1 MHz or less. Generally data is considered valid while SCLK is HIGH, and data is in transition when SCLK is LOW. The clock polarity used with the 3D MagIC is zero (CPOL=0). Data is present on MISO or should be presented on MOSI before the first low to high clock transition (CPHA = 0).

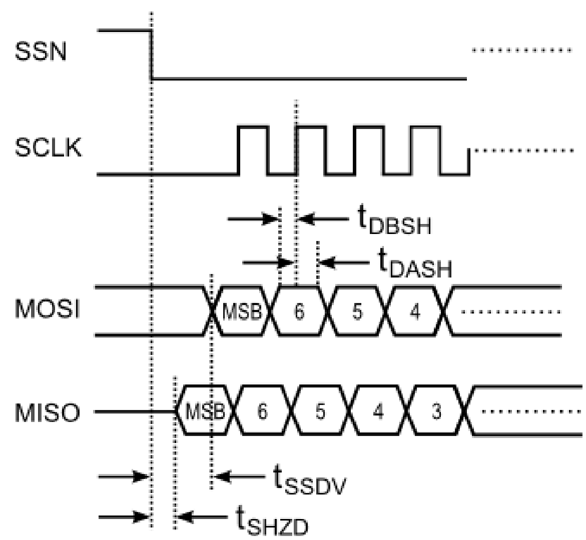

Figure 4-1: SPI Timing Diagram

Table 4-2: SPI Timing Specifications

Symbol	Description	Min	Max	Units
t_{SSDV}	Time from SSN to Command Byte on MOSI	1		us
t_{DBSH}	Time to setup data before active edge	50		ns
t_{DASH}	Time to setup data after active edge	50		ns
t_{SHZD}	Time from SSN to data tri-state time		100	ns

4.4 Idle Mode

The RM3000-f Evaluation Board incorporates an Idle Mode to reduce power consumption, in which the circuit automatically idles when it is not exchanging data or taking a measurement. The RM3000-f Evaluation Board starts in the Idle Mode at power-up and remains in Idle Mode until a measurement is needed.

Note: *The fact that the RM3000-f Evaluation Board starts in Idle Mode at power-up is different from the legacy MicroMag modules, where it was necessary to cycle the MicroMag modules through one measurement request operation at power-up to put them into Idle Mode.*

5 Operation

The basic functions to be performed when operating the RM3000-f Evaluation Board are:

- Setting the values in the Cycle Count Registers, and
- Taking sensor measurements.

The user should first establish the number of cycle counts to be measured for each sensor by writing to the Cycle Count Registers. This is followed by sending a command or series of commands to make the sensor measurements. Assuming the user will use the same number of cycle counts for subsequent measurements, it is not necessary to rewrite to the Cycle Count Registers for subsequent sensor measurements.

The RM3000-f Evaluation Board provides two methods to take sensor measurements, which are discussed later in this section:

- Single-axis measurement (SAM), and
- Multi-axis measurement (MAM).

The SAM Command Byte initiates a measurement for one sensor and sets up the RM3000-f Evaluation Board to write the measured values out on the MISO line. The MAM Command Byte initiates a sensor measurement for up to 3 sensors, and a later Command Byte sets up the module to write the measured values out on the MISO line for up to 3 sensors. For two or three axis measurements, normally it is more efficient to operate using the MAM Command Byte.

5.1 Cycle Count Registers

Prior to sending a command to take a sensor measurement, it is necessary to write values to the Cycle Count Registers. (The default value for the Cycle Count Registers is 512_D, but this was chosen for legacy reasons and is an inefficient value otherwise.) The Cycle Count Registers establish the number of sensor oscillation cycles that will be counted for each sensor in both the forward and reverse bias directions during a measurement sequence. Increasing the cycle count value increases measurement resolution, but system noise limits the useable resolution such that the maximum efficient cycle count value generally is around 200-300 cycle counts. Lowering the cycle count value reduces acquisition time, which increases maximum achievable sample rate or, with a fixed sample rate, decreases power consumption. See Figure 3-1, Figure 3-2, and Figure 3-3 to estimate the appropriate cycle count value for your application. Once the Cycle Count Registers are set, they do not need to be repopulated unless the user wants to change the values or the system is powered down (in which case the default values would populate the register fields when powered up again).

To initiate a read or write from the Cycle Count Register, send the Command Byte:

7	6	5	4	3	2	1	0
RFLAG=1	R/W	0	0	ADR3	ADR2	ADR1	ADR0

R/W: Read/Write

HIGH signifies a Read from the addressed register. LOW signifies a Write operation.

ADR0 – ADR3: Register Address Bits

Establishes which register will be written to or read from. Each sensor is represented by two registers, with addresses defined as follows:

Table 5-1: Cycle Count Register Commands

Register Description	Read Command Byte	Write Command Byte
X Axis Cycle Count Value - MSB	C3H	83_H
X Axis Cycle Count Value - LSB	$C4_H$	84_H
Y Axis Cycle Count Value - MSB	$C5_H$	85_H
Y Axis Cycle Count Value - LSB	$C6_H$	86_H
Z Axis Cycle Count Value - MSB	$C7_H$	87_H
Z Axis Cycle Count Value - LSB	$C8_H$	88_H

Since the registers are adjacent, it is not necessary to send multiple Command Bytes, as the RM3000-f Evaluation Board automatically will read/write to the next adjacent register.

A sample command sequence is provided below which sets the cycle count value to 100_D (64_H) for all 3 axes. This is purely for illustrative purposes and the value could be different and/or the number of axes to be addressed could be different.

- Start with SSN set HIGH, then set SSN to LOW.
- Send 83_H (this is the Write Command Byte to address the MSB for the X axis)
- Send 0 (value for the MSB for the X axis)
- Send 64_H (value for the LSB for the X axis - pointer automatically increments)
- Send 0 (value for the MSB for the Y axis - pointer automatically increments)
- Send 64_H (value for the LSB for the Y axis - pointer automatically increments)
- Send 0 (value for the MSB for the Z axis - pointer automatically increments)
- Send 64_H (value for the LSB for the Z axis - pointer automatically increments)
- Set SSN to HIGH

5.2 Single-Axis Measurement (SAM) Operation

The SAM Command Byte initiates a sensor measurement on a single sensor, and sets up the RM3000-f Evaluation Board to output the measured values on the MISO line. SAM operation is not as efficient as MAM operation except when only one sensor is measured.

5.2.1 SAM SPI Activity Sequence

The SPI activity sequence for SAM operation is given below. SPI timing is discussed in Section 4.3. The Return Byte is $9A_H$. Three (3) data bytes will be clocked out for a single-axis measurement. The Command Byte is discussed below.

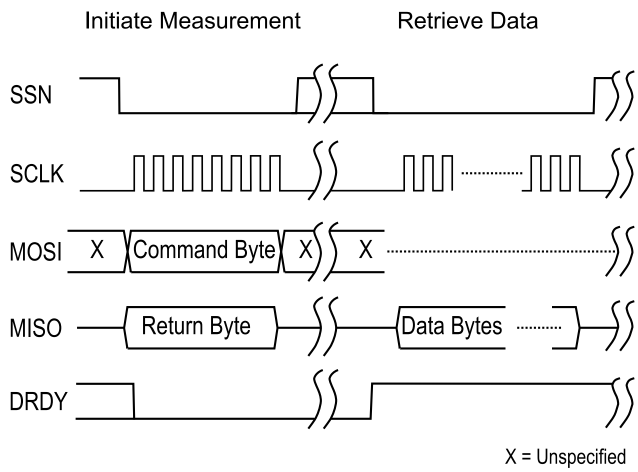

Figure 5-1: SPI Activity Sequence Diagram for SAM Operation

5.2.2 SAM Command Byte

The SAM Command Byte is defined as follows:

Bit #	7	6	5	4	3	2	1	0
Value	0	0	0	0	0	0	AS1	AS0

Table 5-2: SAM Axis Select Bits

Description	AS1	AS0
No axis measured	0	0
X axis (Channel 1)	0	1
Y axis (Channel 2)	1	0
Z axis (Channel 3)	1	1

5.2.3 Making a Single-Axis Measurement

The steps to make a single-axis sensor measurement are given below. The 3D MagIC will return the result of a complete forward- reverse measurement of the sensor in a 24 bit 2's complement format (range: -8388608 to 8388607).

- SSN pin is set LOW. This enables communication with the master device.
- The SAM Command Byte is clocked into the 3D MagIC on the MOSI pin. Simultaneously, the 3D MagIC will present a fixed $9A_H$ on the MISO pin. Once the 8 bits have clocked in, the 3D MagIC will execute the command (i.e. take a measurement).
- The SSN input may be returned HIGH at this point to free up host communication with another device if desired. This will not affect the measurement process.
- A measurement is taken.
- At the end of the measurement, the DRDY pin is set HIGH, indicating data is ready, and the 3D MagIC is placed in Idle Mode.
- The SSN input should be set LOW, if it is not already, to read the data.
- The data is clocked out on the MISO pin with the next 24 clock cycles.

If another measurement is immediately made, SSN can remain LOW and the process repeated. Otherwise it is recommended that SSN is set HIGH to release the SPI bus.

5.3 Multi-Axis Measurement (MAM) Operation

An initial MAM Command Byte initiates a sensor measurement for up to 3 sensors. After the measurements are made and the DRDY line goes HIGH, another MAM Command Byte sets up the RM3000-f Evaluation Board to output the measured values on the MISO line.

5.3.1 MAM SPI Activity Sequence

The SPI activity sequence is given below for MAM operation. SPI timing is discussed in Section 4.3. The Return Byte is $9A_H$. The number of data bytes will be determined by the number of axes that are to be measured. Each axis is comprised of 3 bytes of data, so for a 3 axis measurement 9 total bytes would be clocked out to receive all the data. The Command Byte and Axes Select Byte are discussed below.

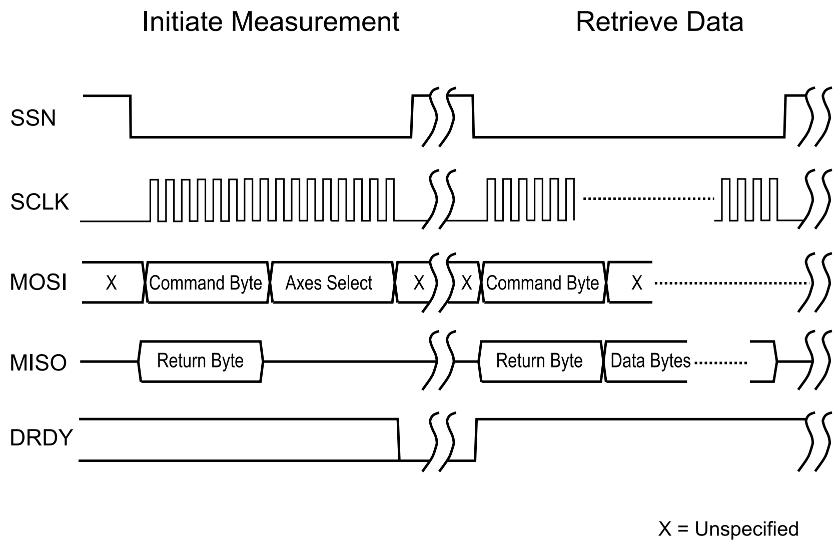

Figure 5-2: SPI Activity Sequence Diagram for MAM Operation

5.3.2 MAM Command Byte

The MAM Command Byte either initiates a sensor measurement or initiates placing the measurement results on the MISO line for the host to read. The MAM Command Byte is 82_H to initiate a sensor measurement and is $C9_H$ to retrieve the data.

Note: *Measurement results are stored in registers and SCLK should be stopped once the measurements are clocked out. If SCLK continues to run after the appropriate number of data bytes for the defined axes, then the data on the MISO line will have little meaning.*

5.3.3 MAM Axes Select Byte

The MAM Axes Select Byte establishes which axes are to be measured, as follows:

Bit #	7	6	5	4	3	2	1	0
Value	0	0	0	AAX1	AAX0	0	0	1

Table 5-3: MAM Axes Select Bits

Axes to be Measured	AAX1	AAX0
X, Y, and Z	0	0
X and Y	0	1
X only	1	0
No axis measured	1	1

5.3.4 Making a Multi-Axis Measurement

The steps to make a multi-axis sensor measurement are given below. The RM3000-f Evaluation Board will return the result of a complete forward- reverse measurement of each sensor in a 24 bit 2's complement format (range: -8388608 to 8388607).

- Start with SSN set HIGH, then set SSN to LOW.
- Initiate a sensor measurement by sending 82_H (MAM Command Byte to write to the Mode Register) followed by 01_H (Mode Register Word to initiate measurement) on the MOSI pin. The RM3000-f Evaluation Board will now take the prescribed measurements.
- Return SSN to HIGH. This will not affect the measurement process, but will free up the host to communicate with other devices and ensure the next Command Byte sent to the module is interpreted properly.
- A measurement is taken.
- At the end of the measurement, the DRDY pin is set HIGH, indicating data is ready, and the RM3000-f Evaluation Board is placed in Idle Mode.
- When the host is ready to read the measured values, set SSN to LOW. If SSN already is LOW, then toggle SSN from LOW to HIGH to LOW.
- Send $C9_H$ (MAM Command Byte to read from the) on the MOSI pin to initiate reading the measurement values. Data is clocked out on the MISO pin. Each sensor reading consists of 3 bytes of data, clocked out MSB first. X-axis data is presented first, then y-axis data, then z-axis data. The first nine (9) bytes represent a complete 3-axis measurement.
- Return SSN to HIGH to free up the host to communicate with other devices and to ensure the next Command Byte sent to the 3D MagIC is interpreted properly.