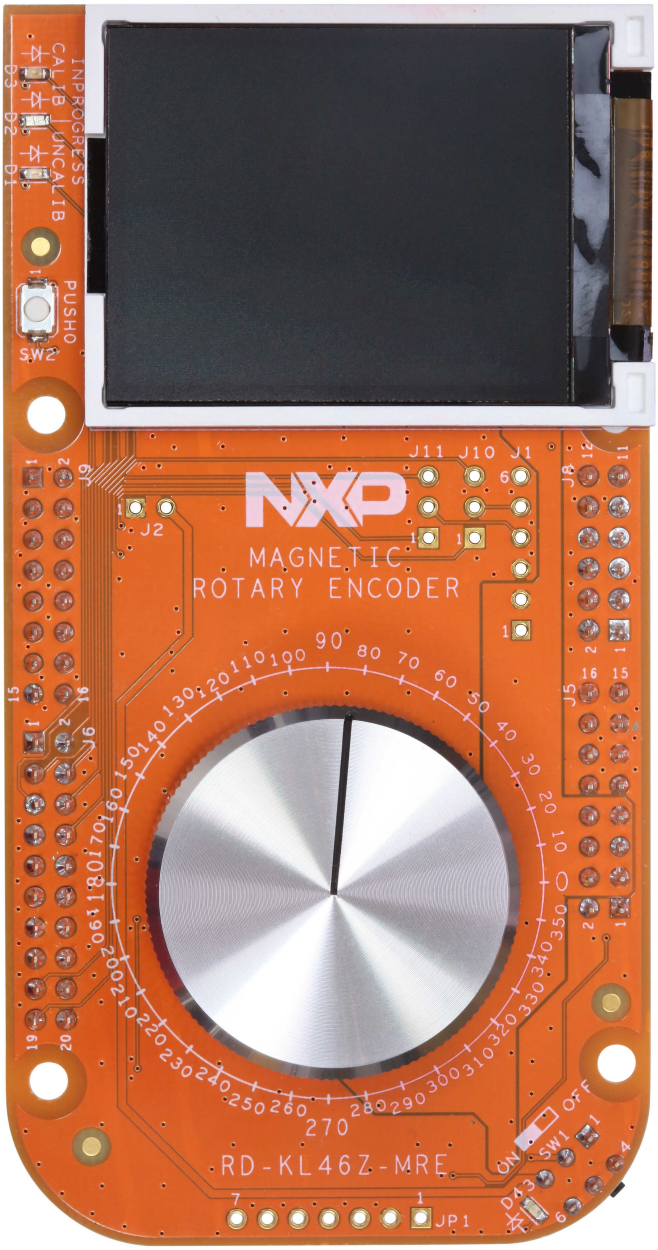
RD-KL46Z-MRE

Magnetic rotary encoder reference design kit

Rev. 1.0 — 2 June 2016 User guide

1 RD-KL46Z-MRE



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3 Getting started

3.1 Kit contents/packing list

The RD-KL46Z-MRE contents include:

- Assembled and tested evaluation module:
  - RD-KL46Z-MRE evaluation board
  - BRKT-STBC-AGM01 breakout board
  - FRDM-KL46Z development board
- USB cable
- Warranty card

3.2 Jump start

All product development boards are accompanied by a Jump Start bundle available on the board's tool summary page. Jump Start bundles offer current versions of the resources related to the board. The bundles provide everything needed to begin using the board in a design environment. To access the Jump Start bundle:

1. Go to nxp.com/RD-KL46Z-MRE.
2. Review your Tools Summary Page.
3. Locate and click:

   Jump Start Your Design

4. Download the documents, software, and other information.

4 Hardware description

The RD-KL-46Z-MRE is a reference design kit that supports system designs based on NXP's FXOS8700CQ, a 6-axis sensor with an integrated linear accelerometer and a magnetometer.

4.1 Kit overview

The kit contains an RD-KL46Z-MRE evaluation board, a BRKT-STBC-AGM01 breakout board, an FRDM-KL46Z development board, and a USB cable with a type-A plug and a Mini-B plug. See Figure 1.

The top board of the RD-KL46Z-MRE demonstrates the magnetic rotary encoder. It is composed of an LCD screen, a knob connected to a diametrically magnetized magnet, and several interfaces to communicate with an external IC.

The middle board, the BRKT-STBC-AGM01 breakout board, contains two NXP sensors:

- FXOS8700, a 6-axis accelerometer and magnetometer
- FXAS21002, a 3-axis gyroscope

The FXOS8700 is used to measure the magnetic field of a magnet. The air gap is not adjustable on the demo board, because of the mechanical parts. However, for a final application (end customer product), the user must make sure the magnetic

field measured by the sensor is within the range of 200 µT and 600 µT to maintain an accurate calibration algorithm.

The bottom board, the FRDM-KL46Z development board, is a simple yet sophisticated design featuring a Kinetis L series microcontroller, built on the ARM® Cortex™-M0+ core.

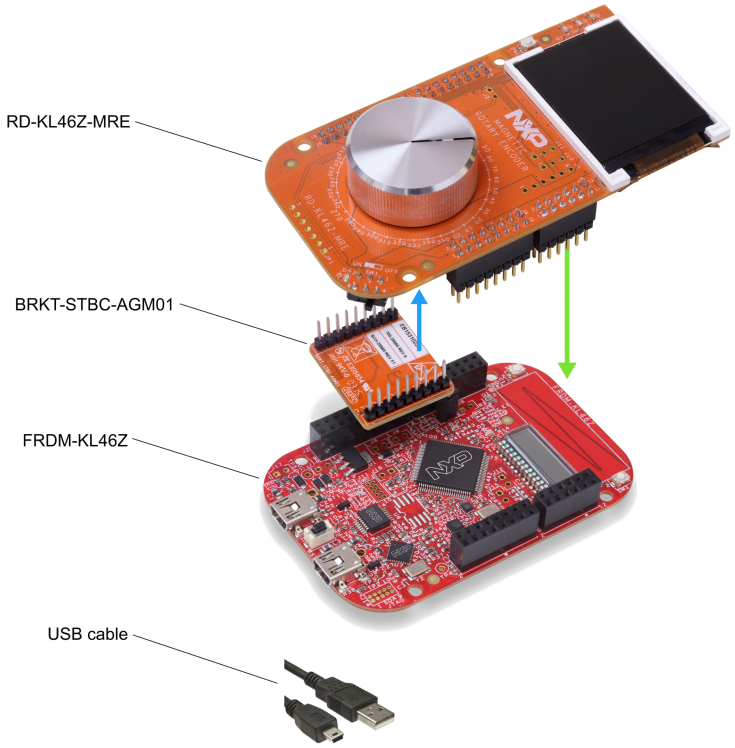

Figure 1. RD-KL46Z-MRE evaluation kit

4.2 Block diagram

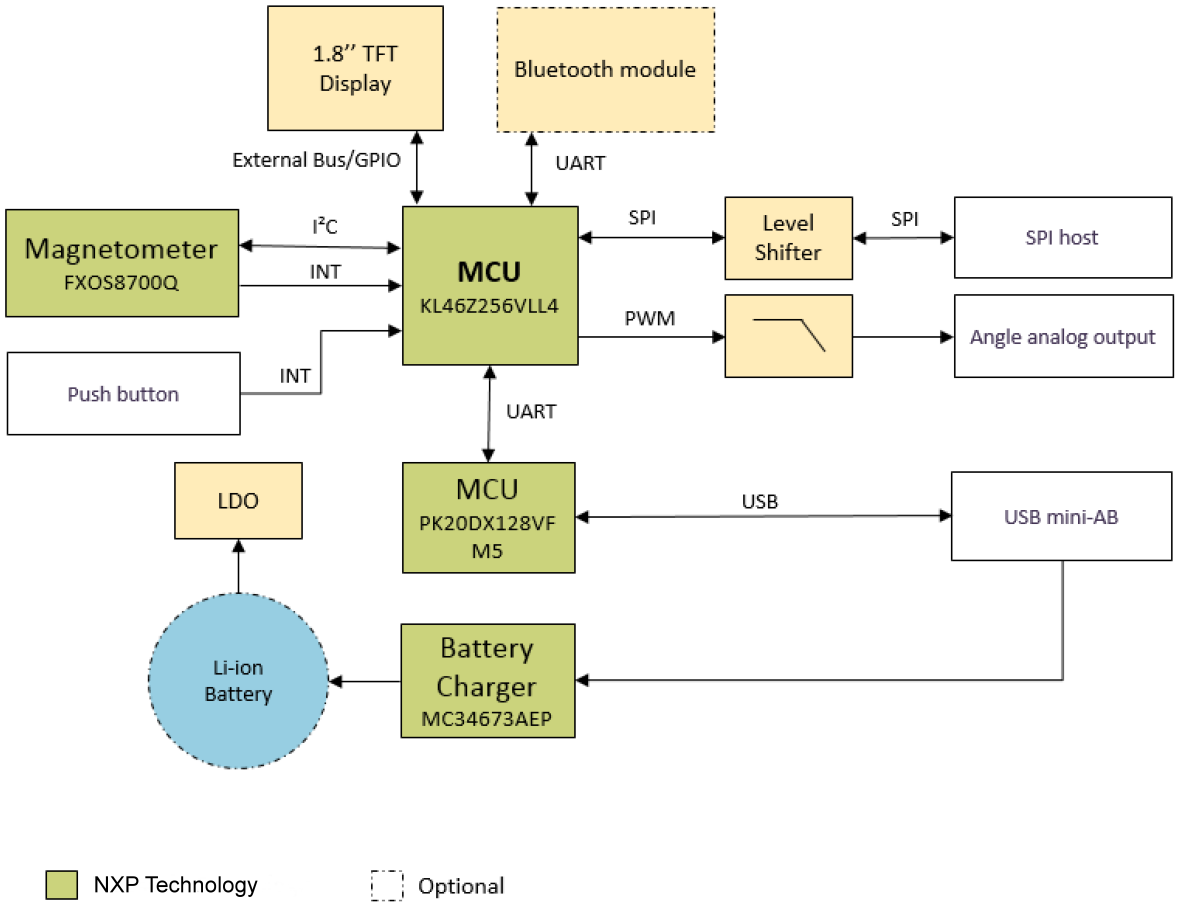

Figure 2. RD-KL46Z-MRE Block Diagram

4.3 Board description

The RD-KL46Z-MRE is a circuit board allowing the user to exercise all the functions of the NXP FXOS8700 magnetometer.

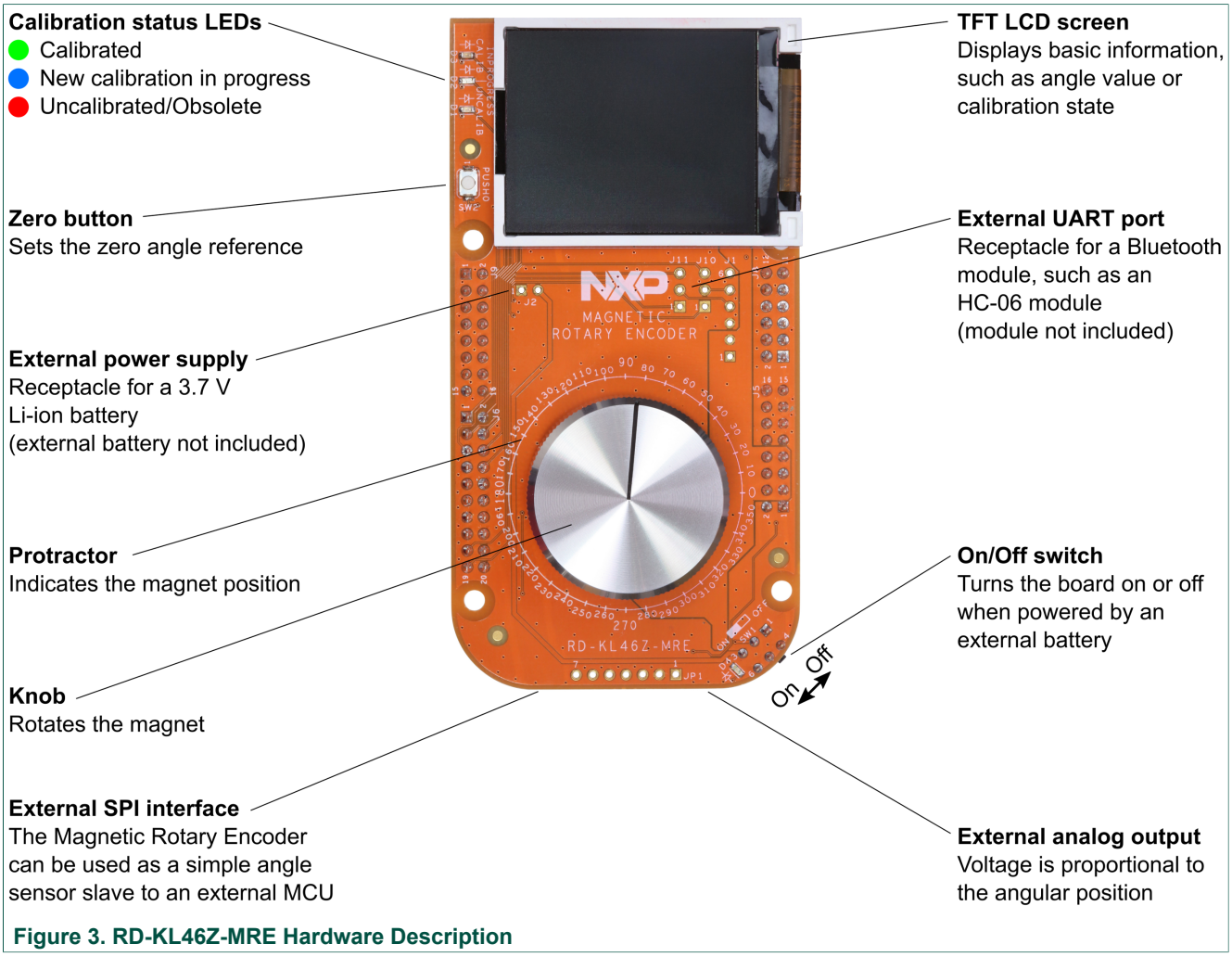

Figure 3. RD-KL46Z-MRE Hardware Description

4.4 Freedom board configuration

The RD-KL46Z-MRE is compatible with the FRDM-KL46Z Freedom evaluation board.

When used in this configuration, the RD-KL46Z-MRE mounts to the surface of the Freedom board by means of the onboard Arduino™ connectors (connectors J1, J2, J9 and J10).

5 Setting up the hardware

5.1 Prepare the drivers

- Plug one end of a USB cable into the OpenSDA port on the FRDM-KL46Z board. Plug the other end of the cable into a USB port on the computer.

After connecting the FRDM-KL46Z board to the computer, Microsoft® Windows® automatically adds the following two devices to the computer's device manager.

- A portable device to flash the MCU
- A serial port to communicate with the board

After the driver installation, the serial port number begining with COM appears. Write this number down for use with the Graphical User Interface (GUI) later.

5.2 Install the GUI

Download the GUI from nxp.com/RD-KL46Z-MRE. Install the NXP Magnetic Rotary Encoder GUI.

5.3 Flash the MCU

Execute the GUI that was just installed. See Figure 4.

1. Click on the **Settings** button.
2. Click on the FRDM-KL46Z picture, and then click the **Flash** button.
3. In the **Browse For Folder** window, click on the drive labeled **FRDM-KL46Z**, and then click **OK**.
4. Wait for a moment, about 20 to 30 seconds.
5. When the board is flashed and ready, and a confirmation dialog box appears, click **OK**. See Figure 5.

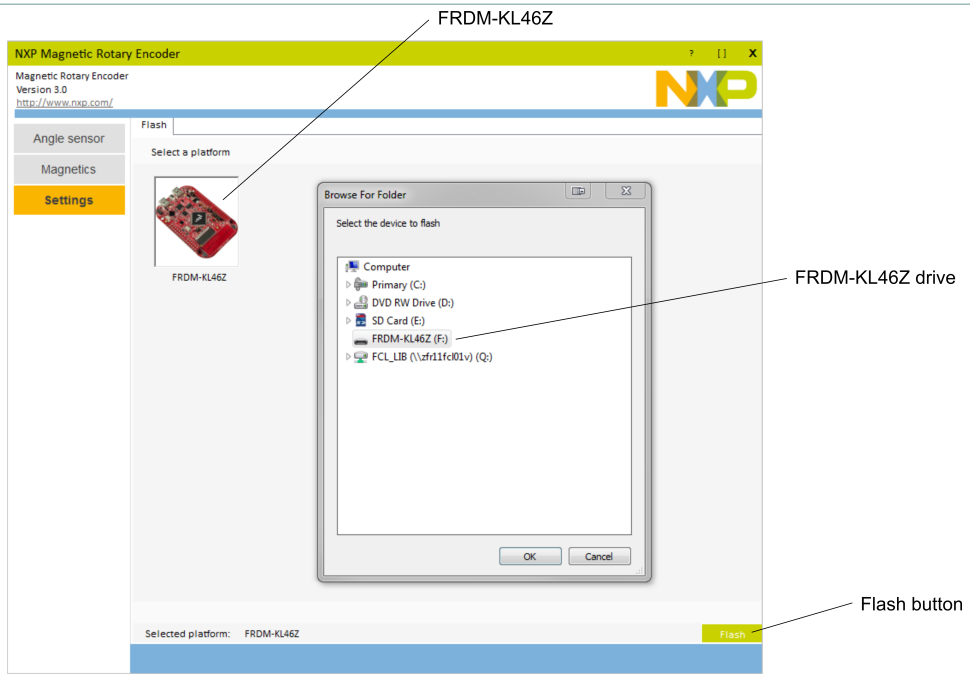

Figure 4. Flash the MCU

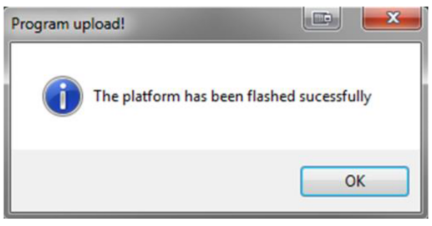

Figure 5. Program upload! window

5.4 Establish communication

The NXP Magnetic Rotary Encoder evaluation board is now ready to be used. Some information is displayed in the embedded LCD screen. Additional parameters and options are available by using the NXP Magnetic Rotary Encoder software. If the MRE software is not running, start the program and complete the following steps.

1. Confirm that the USB cable is still connected to the computer and the evaluation board.
2. Click the **Angle sensor** button. See Figure 6.
3. Click the **Port** drop-down menu and select the appropriate serial port number. This number was acquired in Section 5.1.
4. Click the **Connect** button.

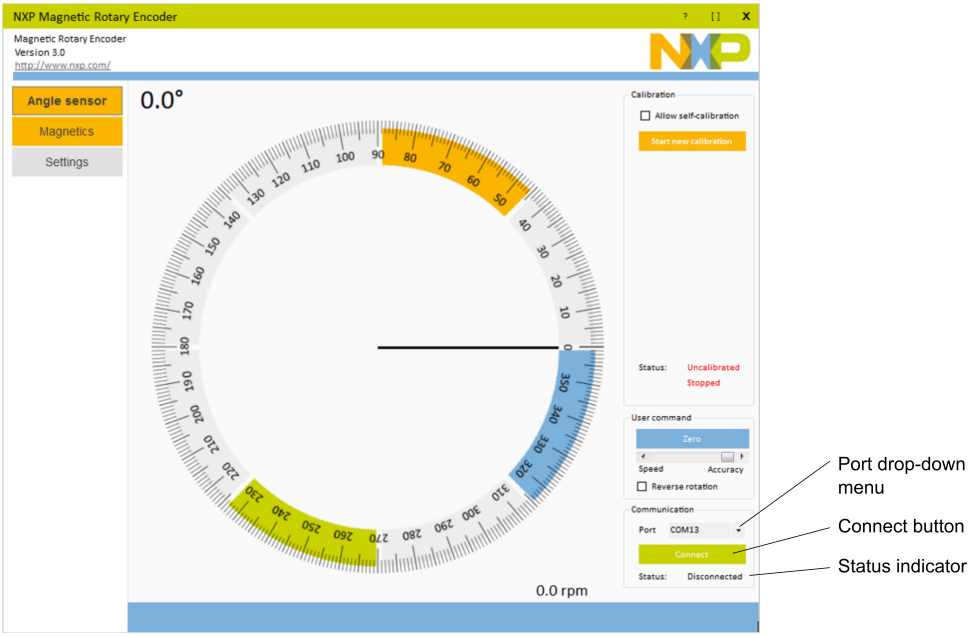

Figure 6. Establishing communication

The status indicator in the Communication panel should change to **Connected**. See Figure 7.

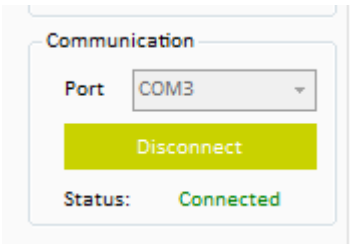

Figure 7. Connected to a computer and communicating

If the board is connected to a computer, but does not communicate with the computer, the status indicator changes to **Failed**. See Figure 8.

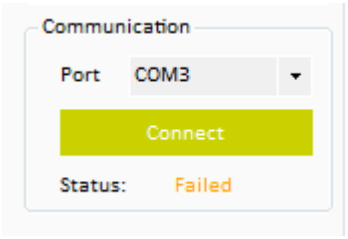

Figure 8. The board is connected to a computer, but not communicating

If the board was communicating with a computer, but the USB cable was disconnected an alert icon appears next to the **Connected** status indicator. The alert icon also appears if an attempt was made to connect to an incorrect port. See Figure 9.

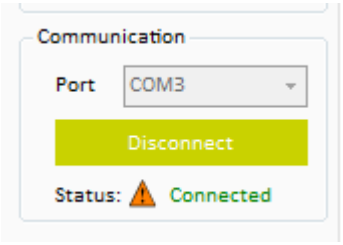

Figure 9. Port com is connected, but there is no response from the rotary board

Clicking on the **Disconnect** buttton changes the status indicator changes to **Disconnected**. See Figure 10.

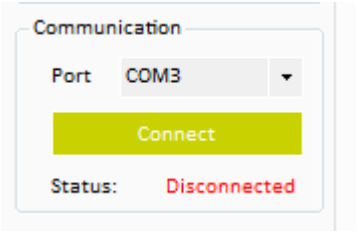

Figure 10. The board is not connected to a computer

5.5 Calibrate the sensor

The first time the board is powered on, the sensor launches a self-calibration phase to correct measured magnetic fields and increase the knob angle position accuracy.

- A blinking red LED indicates that the board is not calibrated.
- A blinking blue LED indicates that the board is collecting the data from the sensor for self-calibration.

To calibrate the sensor, rotate the knob 360 degrees in either direction. This initiates data collection.

When the data collection is finished, the blue LED stops blinking and the knob can be released. When the calibration is computed, the blue LED is turned off. When the calibration is fully functional, the green LED blinks.

Once the board is calibrated, it is necessary to set the zero reference point.

1. Align the cursor knob marker to the zero degree indicator in the proctractor.

2. Press the zero button (SW2) on the board and release, or click on the **Zero** button in the GUI. See Figure 11.

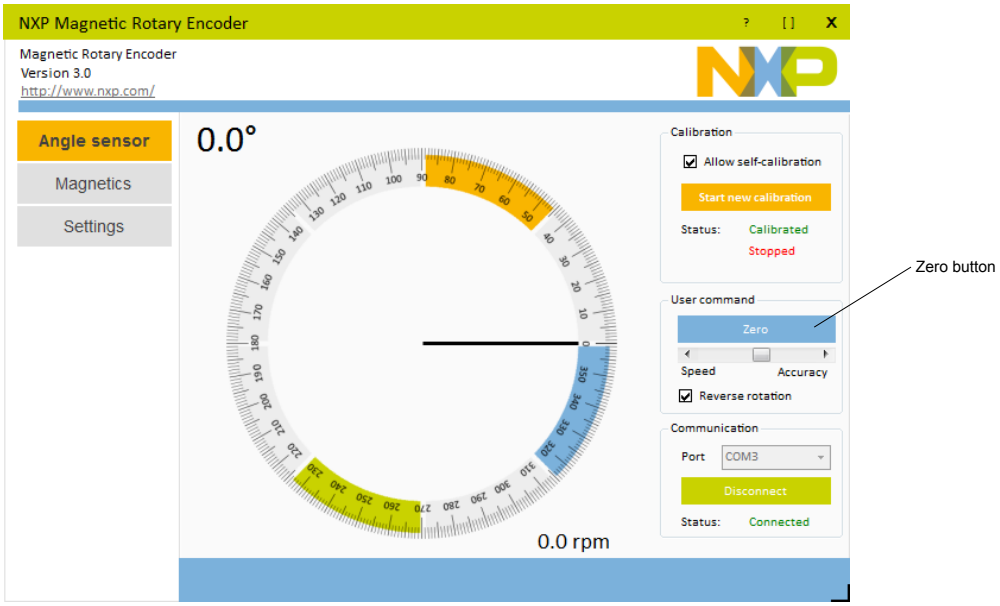

Figure 11. Calibrating the sensor

6 Using the software

Now all functionalities provided by the NXP Magnetic Rotary Encoder GUI are available. Check the figures below and start experimenting.

6.1 Angle sensor window

Clicking on the **Angle sensor** button brings up the main window, see Figure 12. The information in this window is described below.

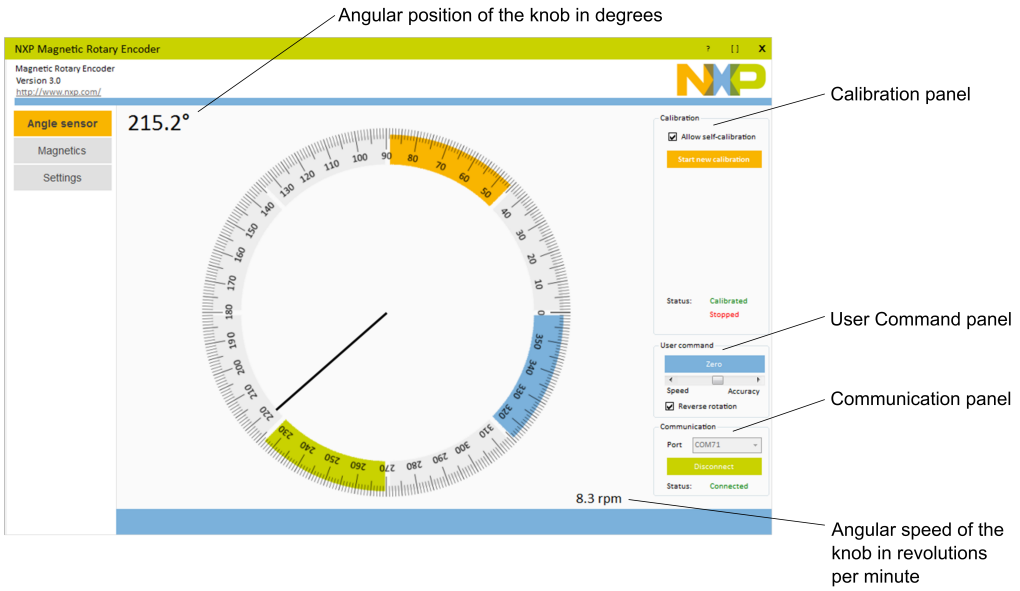

Figure 12. Angle sensor window

- **Knob angular position.** The angular position of the knob in degrees is displayed in the upper left portion of the window.
- **Angular speed.** The bottom right area of the window displays the angular speed. This is the speed, in revolutions per minute, in which the knob is rotated.
- **Calibration panel.** When the **Allow self-calibration** check box is checked, the RD-KL46Z-MRE recalibrates when the current calibration is determined to be obsolete. Clicking on the **Start new calibration** button causes the board to calibrate. The calibration status is displayed in this panel. The various status modes are described later.
- **User command panel**
  - Sets the zero angle reference
  - Sets the accuracy vs. speed ratio
  - Changes the direction of the rotation
- **Communication panel**
  - Selects the serial port number
  - Connects or disconnects the board
  - Displays the communication status

6.2 Magnetics window

Clicking the **Magnetics** button brings up the **Magnetics** window. There are three tabs available in this window: **Time view**, **XY view**, and **Angle error view**. Each of these views is described in the following sections.

6.2.1 Time view

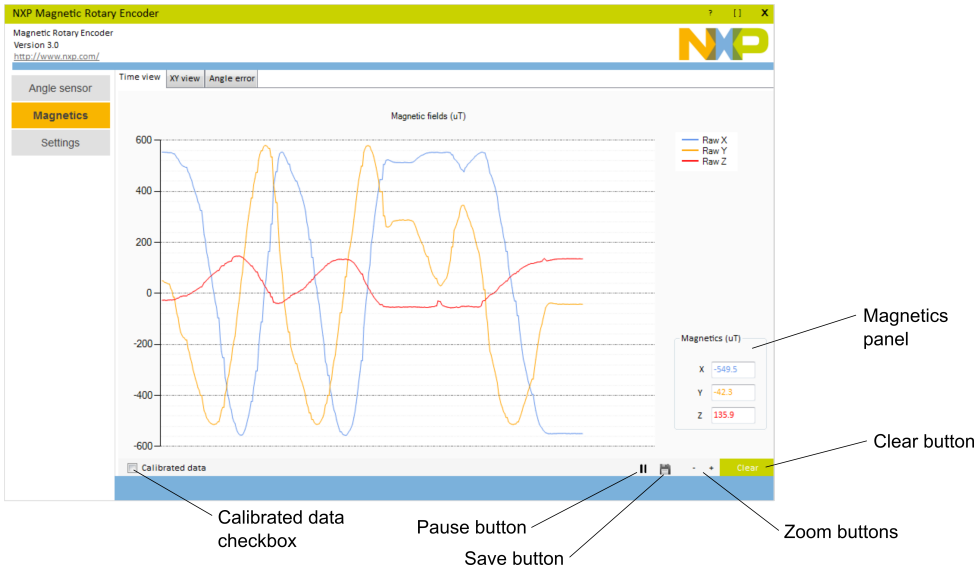

Figure 13. Time view

- **Magnetics panel.** The magnetic field values in each of the three axes (X,Y,Z) are displayed in real time.
- **Clear button.** Clicking this button clears the current graph and begins a new graphing session.
- **Zoom buttons.** These buttons control the range displayed in the graph.
  - Clicking the **+** (plus) button increases the amount of data shown per second. The graph scrolling speed increases.
  - Clicking the **–** (minus) button decreases the amount of data shown per second. The graph scrolling speed decreases.
- **Save button.** Clicking this button saves the current paused graph to a .csv file.
- **Pause button.** Clicking this button stops the current graph, making it available to save. Clicking it again resumes the graphing session.
- **Calibrated data check box.** When **Calibrated** data is set, the calibrated data is shown. When the check box is clear, the graph displays uncalibrated data.

6.2.2 XY view

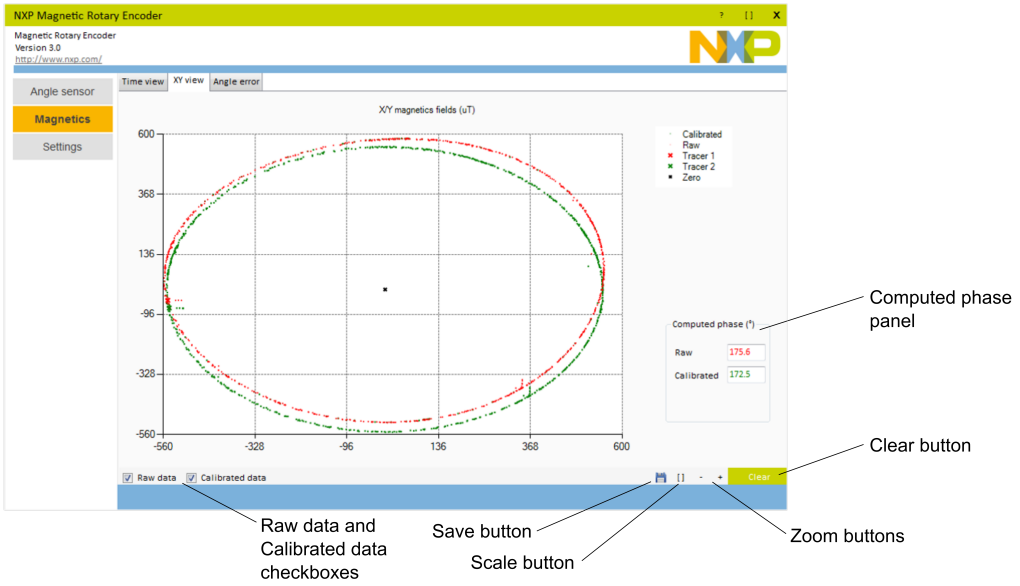

Figure 14. X/Y view

- **Computed phase panel.** Raw and calibrated angle values, in degrees, are displayed.
- **Clear button.** Clicking this button clears the current graph and begins a new graphing session.
- **Zoom buttons.** These buttons control the weight of each point displayed in the graph.
  - Clicking the **+** (plus) button increases the weight (pixel size) of each data point.
  - Clicking the **–** (minus) button decreases the weight (pixel size) of each data point.
- **Scale button.** Clicking this button rescales the chart to best fit the window.
- **Save button.** Clicking this button saves the current paused graph to a .csv file.
- **Raw data and Calibrated data check boxes.** When there is a check in each check box, the corresponding data is displayed.

6.2.3 Angle error view

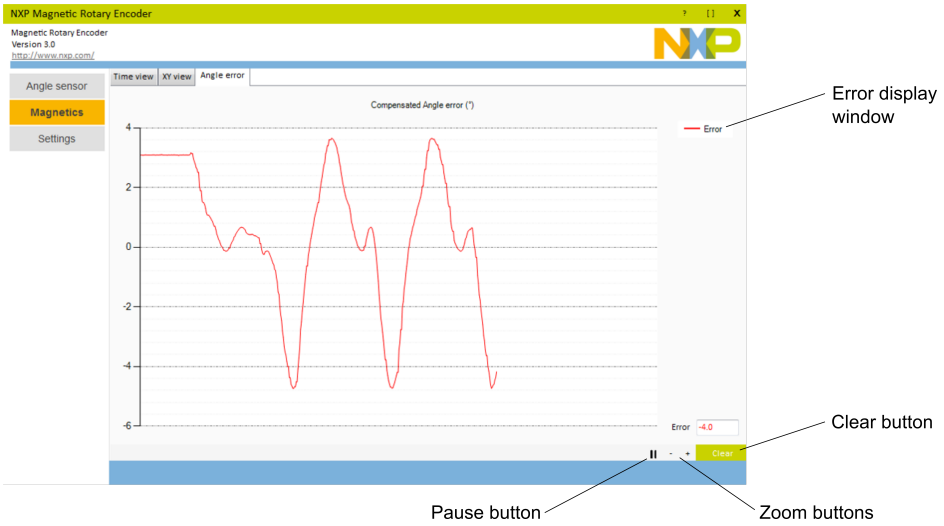

Figure 15. Angle error view

- **Error display window.** The difference in degrees between the raw angle and the calibrated angle. The value displayed is the angle correction added to the raw value.
- **Clear button.** Clicking this button clears the current graph and begins a new graphing session.
- **Zoom buttons.** These buttons control the range displayed in the graph.
  - Clicking the **+** (plus) button increases the amount of data shown per second. The graph scrolling speed increases.
  - Clicking the **–** (minus) button decreases the amount of data shown per second. The graph scrolling speed decreases.
- **Pause button.** Clicking this button stops the current graph, making it available to save. Clicking it again resumes the graphing session.

7 Understanding calibration state and self-calibration

The various calibration states available are described in this section. See Figure 16. Understanding these states helps make the algorithm easier to comprehend.

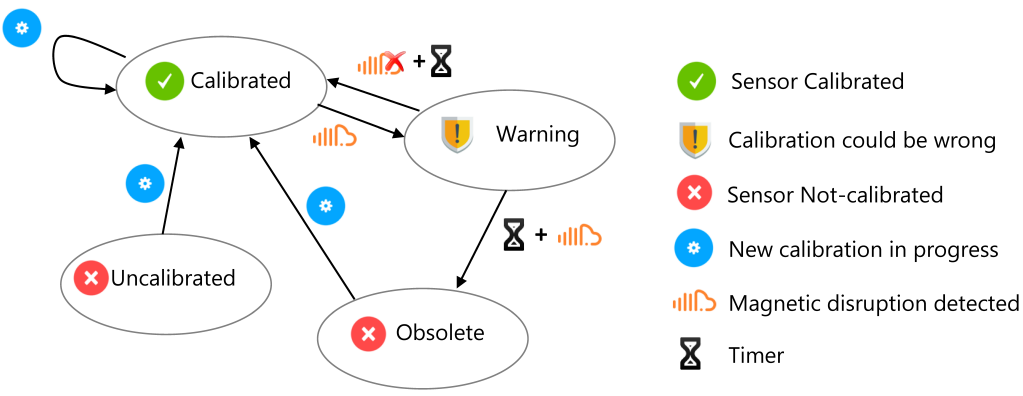

Figure 16. Calibration

The sensor can be in four different states:

- Uncalibrated
- Calibrated
- Warning
- Obsolete

When the RD-KL46Z-MRE is powered up for the first time, the calibration state is Uncalibrated. The self-calibration option is initially enabled; therefore, the board begins a new calibration cycle. Completion of this cycle requires turning the knob one complete rotation in either direction.

The self-calibration mode can be disabled by clearing the **Allow calibration** check box in the **Angle sensor** tab.

If an unusual magnetic disruption is detected, the calibration state changes to Warning and the LEDs change color to orange. When the disruption ends, the calibration state changes to Calibrated. If the disruption continues for a few seconds, the calibration state changes to Obsolete. During the Obsolete state, the sensor continues to use the previous calibration profile, even though it is considered by the system to be obsolete. If the Self-calibration mode is enabled, the sensor continues to attempt to return to the Calibrated state.

8 Understanding data output

The GUI offers several data visualizations and configurations. The next diagram summarizes the data processing chain. This diagram is published for guidance purposes and is not exhaustive.

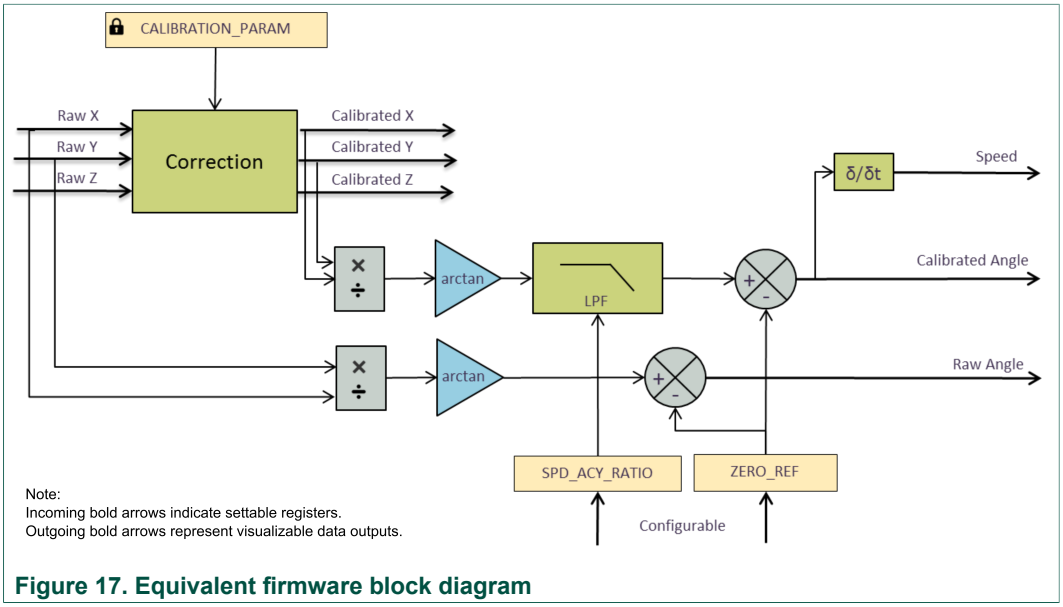

Figure 17. Equivalent firmware block diagram

9 Advanced operations

9.1 Customizing the RD-KL46Z-MRE

The RD-KL46Z-MRE reference design offers different add-ins to improve and test your design:

- An external power supply to make the kit autonomous
- A UART interface to connect to other modules, such as a Bluetooth® module
- A filtered PWM output mode to use a simple analog-to-digital converter with an external MCU as a way of providing the knob angle
- A slave SPI communication to configure and acquire data with an external MCU

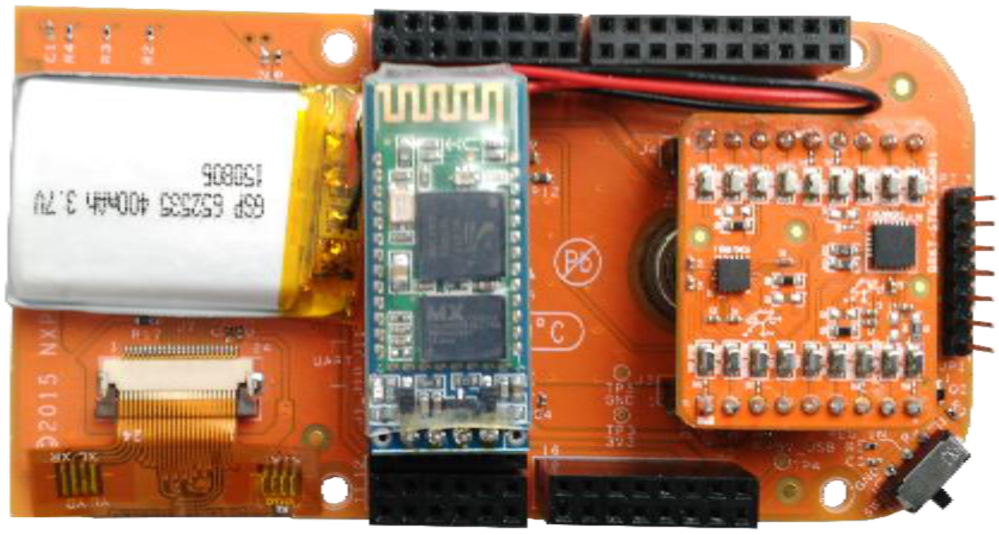

Figure 18. Customized RD-KL46Z-MRE board with battery and Bluetooth® module

9.2 PWM output

The analog output provides the calibrated angle value. The output value is between 0 V and 3.3 V, the latter being the board power supply. The output voltage is proportional to the knob angle: the full scale is 0 V to 3.3 V for 0° to 360°, therefore the resolution is 0.00916 V/°.

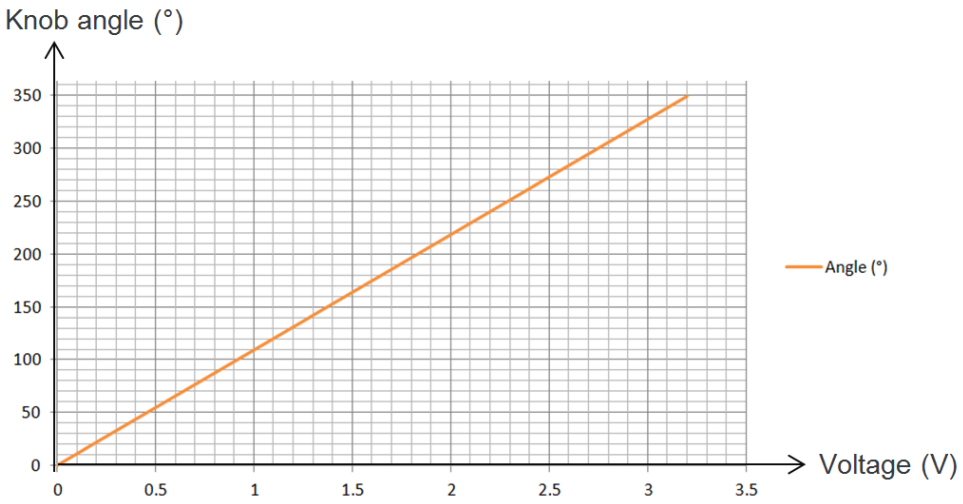

Figure 19. Ratio of output voltage to knob angle

To use this functionality, plug the ANGLE pin to an MCU analog-to-digital input (ADC). Remember to connect the grounds together (GND pin to MCU GND).

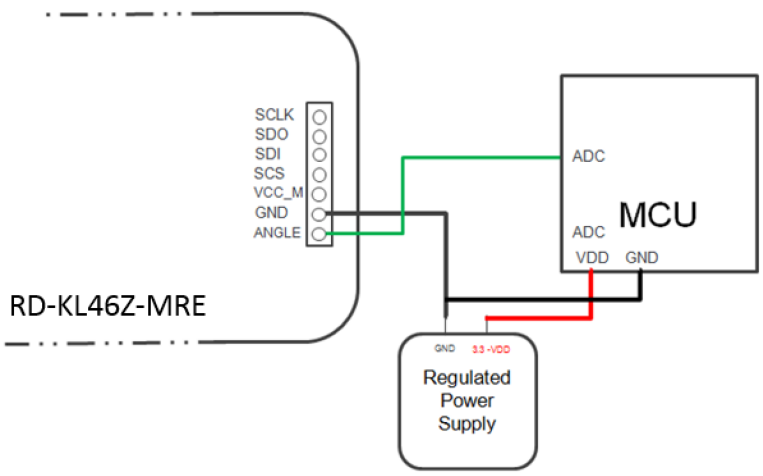

Figure 20. How to connect MCU to the sensor PWM output

9.3 SPI bus

It is possible to control, configure and read data from the magnetic angle sensor by using the SPI bus. Note that the bus is 1.8 V to 5.5 V compliant, and that its maximum speed is 12 MHz. Remember to connect the external MCU supply voltage to the VCC_M and GND pins.

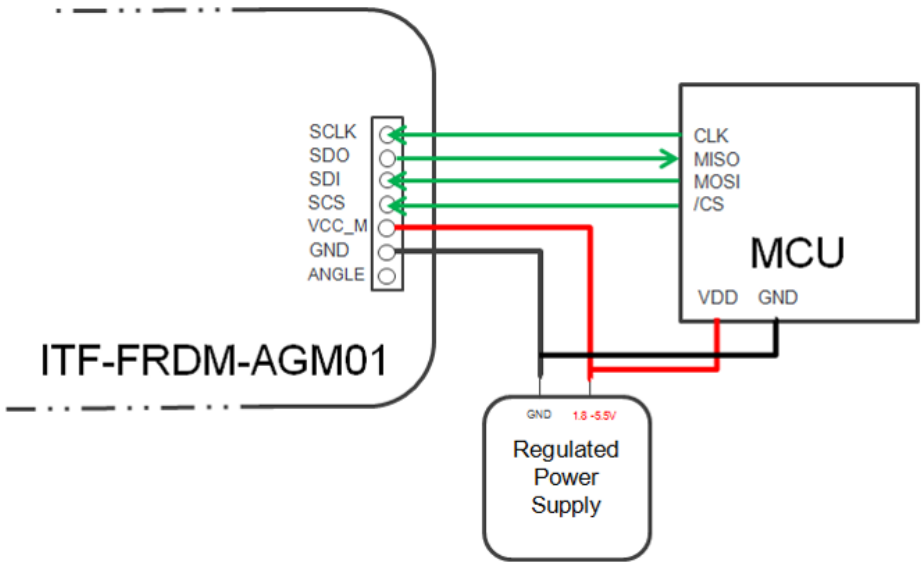

Figure 21. How to connect the sensor to SPI bus

The SPI bus has to be configured in Mode 0 (polarity and phase to low level) for 8-bit transfer. To read or write to a register, you must reset the chip select pin (SCS-/CS).

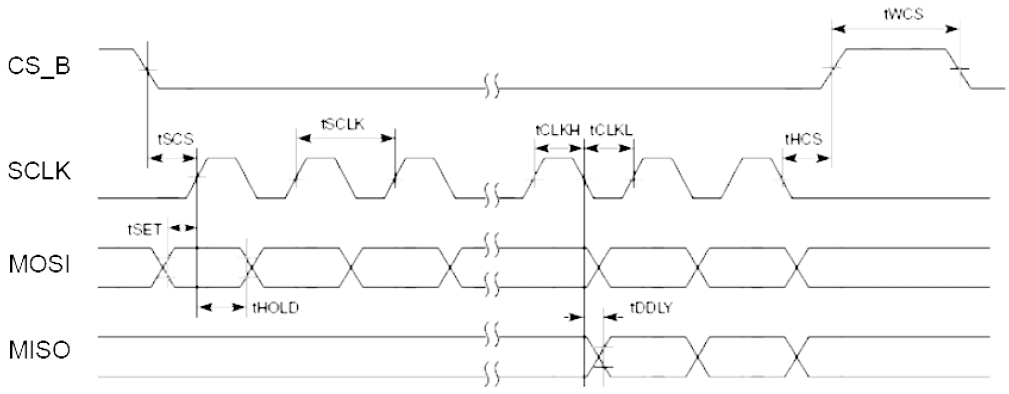

Figure 22. Timing diagram

9.4 Register descriptions

Table 1. Register address map

Name	Type	Register address	Auto-increment address	Reset	Comment
STATUS	R	0x00	0x01	0x03	Real Time calibration status
CTRL_REG	W	0x20	0x02	0x00	Configuration register
WHO_AM_I	R	0x0D	0x03	0x0A	Device ID
ANGLE_MSB	R	0x01	0x04	0x00	[7:0] are the 8 MSBs of the 16-bit real time angle value
ANGLE_LSB	R	0x02	0x05	0x00	[7:0] are the 8 LSBs of the 16-bit real time angle value
SPEED_MSB	R	0x03	0x06	0x00	[7:0] are the 8 MSBs of the 16-bit real time speed value
SPEED_LSB	R	0x04	0x00	0x00	[7:0] are the 8 LSBs of the 16-bit real time speed value

9.4.1 STATUS - Status register (address 00h)

Table 2. STATUS - Status register (address 00h) bit allocation

Bit	7	6	5	4	3	2	1	0
Symbol	reserved		mag_range	cal_prog	cal_state [1:0]		rev_rot	self_cal
Reset	—	—	0	0	0b00		1	1
Access	R	R	R	R	R	R	R	R

Table 3. STATUS - Status register (address 00h) field descriptions

Bit	Symbol	Description
5	mag_range	Set to 1 if the magnetic field read by the sensor is adequate for the calibration and the correction 0: Magnetic field is not in the angle sensor range (default) 1: Magnetic field is in the angle sensor range
4	cal_prog	Set when a new calibration phase is in progress 0: The calibration phase is stopped (default) 1: A calibration phase is running
3 to 2	cal_state [1:0]	Describes the sensor calibration state 0b00: Sensor is not calibrated (default) 0b01: Sensor is calibrated 0b10: Sensor is in warning state 0b11: Sensor calibration is obsolete

Bit	Symbol	Description
1	rev_rot	Indicates if the rotation direction is reversed 0 : Rotation direction is not reversed 1 : Rotation direction is reversed (default)
0	self_cal	Set to 1 if the self-calibration is enabled 0 : Self-calibration is disabled 1 : Self-calibration is enabled (default)

9.4.2 CTRL_REG - Control register (address 20h)

Table 4. STATUS - Status register (address 20h) bit allocation

Bit	7	6	5	4	3	2	1	0
Symbol	reserved			stop_cal	start_cal	ref_zero	rev_rot	self_cal
Reset	—	—	—	0	0	0	0	1
Access	W	W	W	W	W	W	W	W

Table 5. CTRL_REG - Control register (address 20h) field descriptions

Bit	Symbol	Description
4	stop_cal	Controls the calibration stop. 0: no effect (default) 1: stop the current calibration phase (no effect if not InProgress)
3	start_cal	Controls the calibration start 0: No effect (default) 1: Start a new calibration phase (no effect if already InProgress)
2	ref_zero	Sets the current read angle as the zero angle reference 0: No effect (default) 1: Set the angle value to zero
1	rev_rot	Indicates if the rotation direction is reversed 0 : Keep the initial rotation direction (default) 1 : Reverse the rotation direction
0	self_cal	Set to 1 if the self-calibration is enabled 0 : Disable self-calibration 1 : Enable self-calibration (default)

9.4.3 WHO_AM_I - Device identification register (address 0Dh)

Table 6. WHO_AM_I - Device identification register (address 0Dh) bit allocation

Bit	7	6	5	4	3	2	1	0
Symbol	who_am_i [7:0]							
Reset	1	0	1	0	1	0	1	0
Access	R	R	R	R	R	R	R	R

Table 7. WHO_AM_I - Device identification register (address 0Dh) field description

Bit	Symbol	Description
7 to 0	who_am_i	This register contains the NXP unique sensor product identifier and is factory programmed to 0xAA

9.4.4 ANGLE_MSB - Angle output data register (address 01h)

Table 8. ANGLE_MSB - Angle output data register (address 01h) bit allocation

Bit	7	6	5	4	3	2	1	0
Symbol	angle_msb [7:0]							
Reset	0	0	0	0	0	0	0	0
Access	R	R	R	R	R	R	R	R

Table 9. ANGLE_MSB - Angle output data register (address 01h) field description

Bit	Symbol	Description
7 to 0	angle_msb	This register contains the angle sample data. The resolution is 0.00593°/bit, which matches to the full degree scale (0 to 360°) divided by the number of combinations in an unsigned 16-bit register.

9.4.5 ANGLE_LSB - Angle output data register (address 02h)

Table 10. ANGLE_LSB - Angle output data register (address 02h) bit allocation

Bit	7	6	5	4	3	2	1	0
Symbol	angle_lsb [7:0]							
Reset	0	0	0	0	0	0	0	0
Access	R	R	R	R	R	R	R	R

Table 11. ANGLE_LSB - Angle output data register (address 02h) field description

Bit	Symbol	Description
7 to 0	angle_lsb	This register contains the angle sample data. The resolution is 0.00593°/bit, which matches to the full degree scale (0 to 360°) divided by the number of combinations in an unsigned 16-bit register.

9.4.6 SPEED_MSB - Speed output data register (address 03h)

Table 12. SPEED_MSB - Speed output data register (address 03h) bit allocation

Bit	7	6	5	4	3	2	1	0
Symbol	speed_msb [7:0]							
Reset	0	0	0	0	0	0	0	0
Access	R	R	R	R	R	R	R	R

Table 13. SPEED_MSB - Speed output data register (address 03h) field description

Bit	Symbol	Description
7 to 0	speed_msb	ThIs register containS the angular speed sample data expressed as 2's complement numbers. The resolution is 0.8442 rad/s/bit, which matches to the full scale of [–15.000; +15.000 rad/sec] divided by the number of combinations in a signed 16-bit register.

9.4.7 SPEED_LSB - Speed output data register (address 04h)

Table 14. SPEED_LSB - Speed output data register (address 04h) bit allocation

Bit	7	6	5	4	3	2	1	0
Symbol	speed_lsb [7:0]							
Reset	0	0	0	0	0	0	0	0
Access	R	R	R	R	R	R	R	R

Table 15. SPEED_LSB - Speed output data register (address 04h) field description

Bit	Symbol	Description
7 to 0	speed_lsb	ThIs register containS the angular speed sample data expresser as 2's complement numbers. The resolution is 0.8442 rad/s/bit, which matches to the full scale of [–15.000; +15.000 rad/sec] divided by the number of combinations in a signed 16-bit register.

10 Revision history

Revision	Date	Description of changes
1.0	6/2016	Initial release

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Tables

Figures

Contents

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