TI Designs
Ultra-Low-Power Flow Meter Using TMR Sensors Reference Design for Extended System Longevity

TEXAS INSTRUMENTS

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Design Resources

TIDM-TMR-WATERMTR	Design Folder
MSP430FR6989	Product Folder
EVM430-FR6989	Tools Folder

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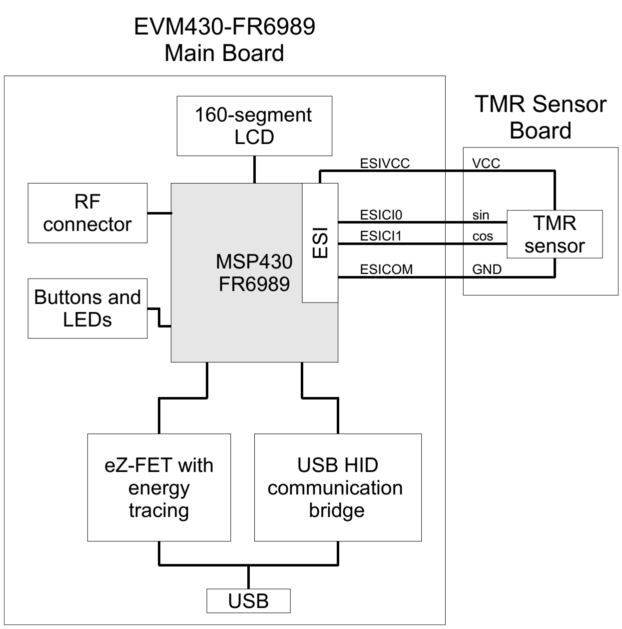
Design Features

- Daughter TMR Sensor Board for EVM430-FR6989
- Rotation Detection Using TMR Sensors
- Example for Calibration
- Ultra-Low Power to Use With ESI

Featured Applications

- Flow Meter
- Gas Meter
- Heat Meter
- Rotation Detection



1 System Description

When designing battery-powered applications, ultra-low power consumption is the key factor in extending the lifetime of a system. Long-running designs must not waste the energy they are provided. This TI design highlights the usage of TMR sensor and Extended Scan Interface (ESI) to archive ultra-low power rotation detection for flow meter application. The evaluation kit EVM430-FR6989 is used for this test.

1.1 MSP430FR6989

The MSP430FR6989 is an MSP430™ ultra-low-power FRAM platform that combines a uniquely embedded FRAM and a holistic ultra-low-power system architecture, allowing innovators to increase performance at lowered energy budgets. FRAM technology combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash at a much lower power.

1.1.1 ESI

The built-in ESI module measures linear or rotational motion automatically with the lowest possible power consumption. The ESI consists of two analog front ends and several processing units. The analog front end stimulates the sensors, senses the signal levels, and converts them into their digital representation. The processing units analyze the signals and count rotation or motion. The MCU is not involved for the measurement process and stays in sleep mode. Therefore, the system current can be kept as low as possible.

1.2 TMR Sensor

Tunnel magnetoresistance (TMR) is a magnetoresistive effect that occurs in a magnetic tunnel junction (MTJ) that consists of two ferromagnets separated by a thin insulating film. The electrons that pass through the insulating film depend on the direction of the magnetizations of those two ferromagnets. Such phenomenon can be translated into electrical resistance that is favorable for measuring magnetic field direction using microcontrollers.

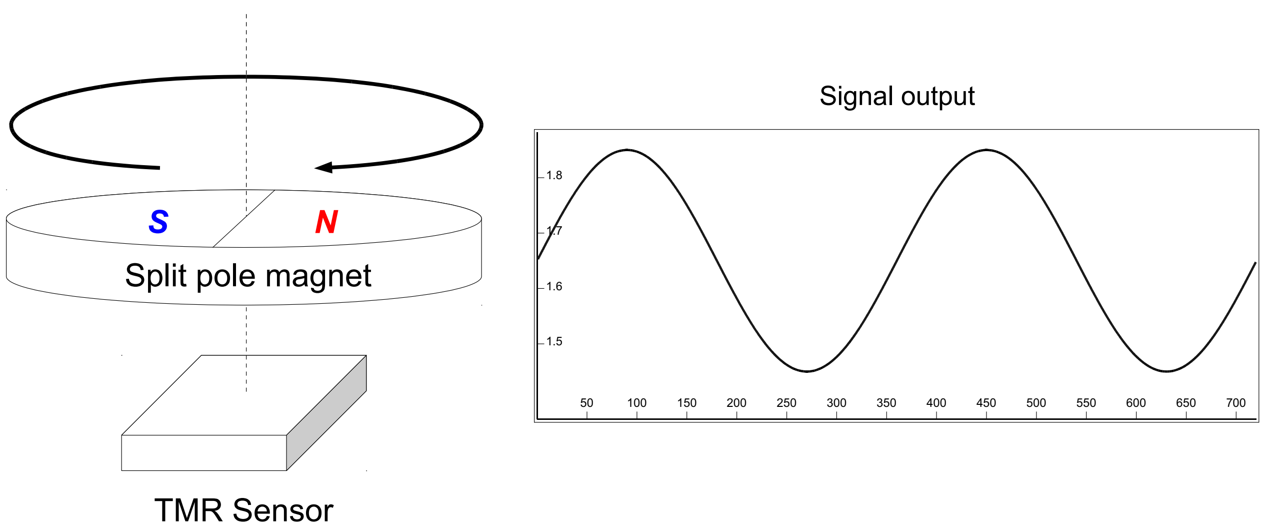


Figure 1. TMR Sensor

1.3 EVM430-FR6989

The EVM430-FR6989 evaluation kit is used to get the test result for this TI Design. This water meter reference design kit is an easy-to-use evaluation module for the MSP430FR698x family of microcontrollers. The kit consists of three boards: the main board, the sensor board, and the motor board.

The main board of the EVM consists of the MSP430FR6989 with different user interfaces such as LCD, buttons, and LEDs. The built-in eZ-FET enables direct programing to the MCU without extra FET tools. The eZ-FET also supports EnergyTrace™ technology to monitor power consumption of the system. The MSP430FR6989 also supports EnergyTrace++™ to monitor the usage of different modules inside the MCU.

Designed for flow meter applications, the sensor board is a daughter board consisting of two LC sensors. The sensors are connected to the ESI module of the MSP430FR6989. Designers can design their own sensor boards for any specific applications that use ESI. In this TI Design, this LC board is not used and replaced by the TMR sensor board.

The motor board drives the rotor disc to simulate water or gas flow. The buttons control the rotating direction of the disc while the variable resistor controls the rotating speed. Visit the device's product page for a detailed description.

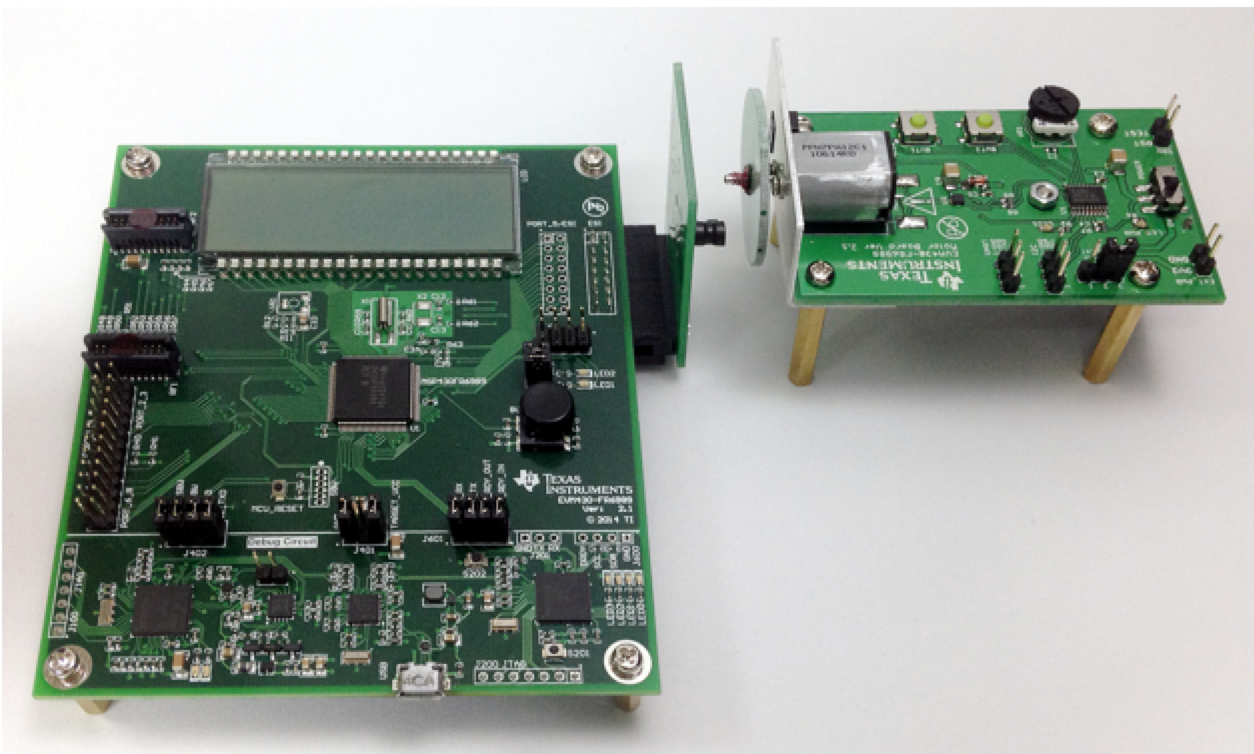


Figure 2. EVM430-FR6989 Evaluation Kit

2 System Design Theory

Because the analog frontend of the ESI provides most of the components for measurement, the hardware configuration of the external sensor circuit is simple. The outputs of the TMR sensor is connected to the comparator inputs of the ESI, while the supply voltage of the TMR sensor is connected to ESIDVCC that is also connected to DVCC of the MCU. The GND of the TMR sensor is connected to the ESICOM instead of the system GND. This connection lowers the system current as described in Section 2.2.

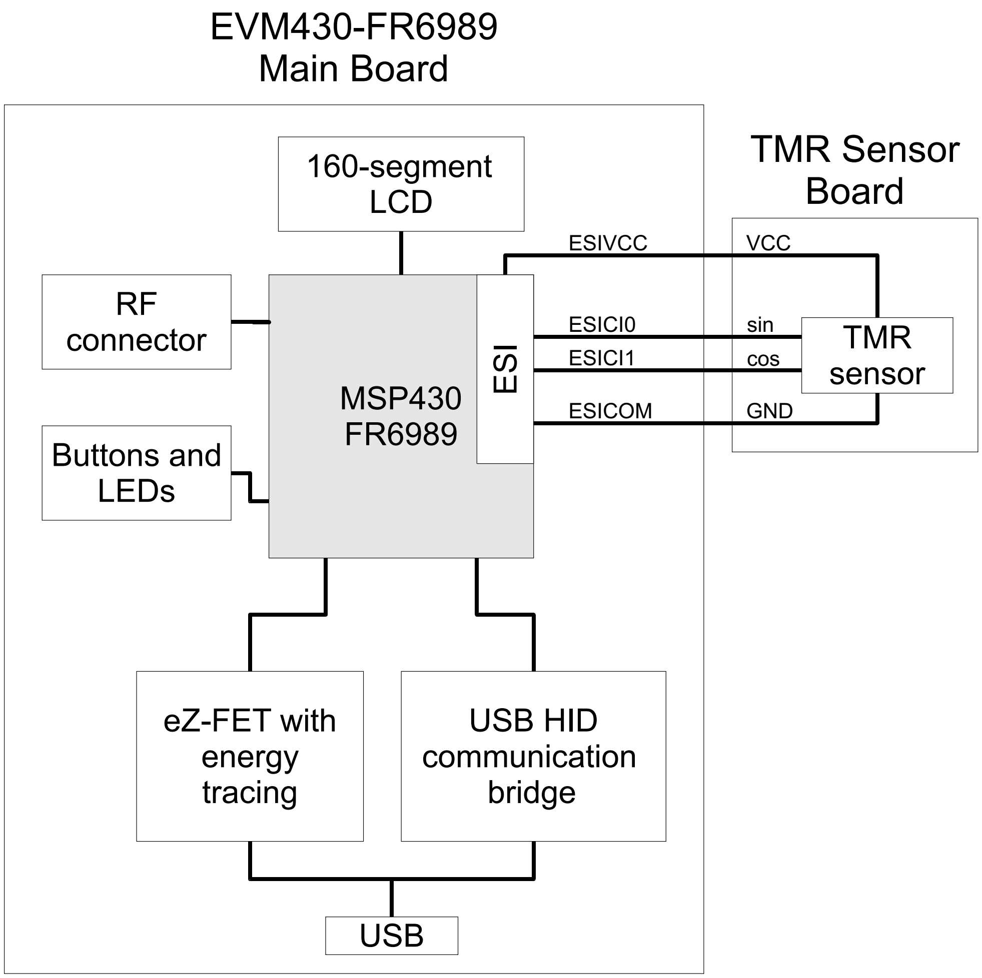


Figure 3. Block Diagram

2.1 TMR Sensor

The sensor tested is the AAT001-10E TMR angle sensor, which is designed for rotation detection. The sensor consists of four sensor elements providing two output signals. The direction of the magnetic field that applies on the sensor controls the output signal level. The two output signals are 90 degrees out of phase that makes direction detection possible. The high resistance of the sensors helps to decrease power consumption for the measurement.

2.2 ESI

With the ESI configured properly, the rotation measurement can be automated and the power consumption can be kept low. Since the measurement only takes few microseconds, the ESICOM is set to flow state at ESI idle state so that the TMR sensor consumes zero current. When the measurement starts, the ESICOM is connected to the ground to enable the TMR sensor. The sensor sends output signals to the ESI comparator. The ESI compares the sensor signal level with the internal DAC reference voltage and generates digitized signals. The processing state machine of the ESI analyses the digitized signals and determines the rotation status of the magnetic field.

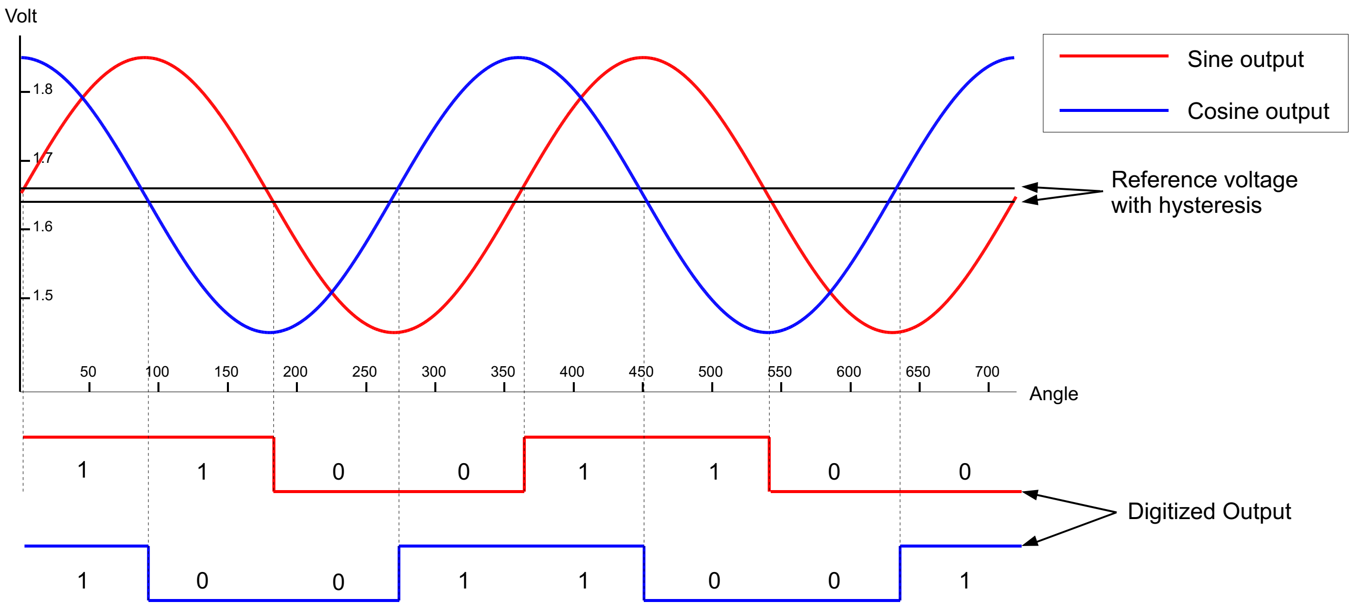


Figure 4. Quadrature Output Enables Direction Detection

3 Software Description

The software setup is also kept simple to minimize power consumption. When the system starts, the hardware modules, such as the clock system and the ESI, are initialized. Then, the calibration starts to find the suitable reference voltage for rotation detection. The calibration requires the magnet to rotate to find the maximum and minimum output voltage of the TMR sensor. After the calibration completes, the ESI interrupts are set up. The system then goes to a low-power mode. The system wakes up when the navigation button is pressed or the ESI interrupts are triggered to update the LCD. The upper part of the LCD shows the sampling rate of the ESI measurement while the lower part shows the ESI counter number. If the navigation button is pressed upward, the sampling rate of the measurement increases. If it is pressed downward, the sampling rate of the measurement decreases. The LCD is toggles if the center is pressed. The LCD shows the sampling rate for 1 second if the LCD is toggled off.

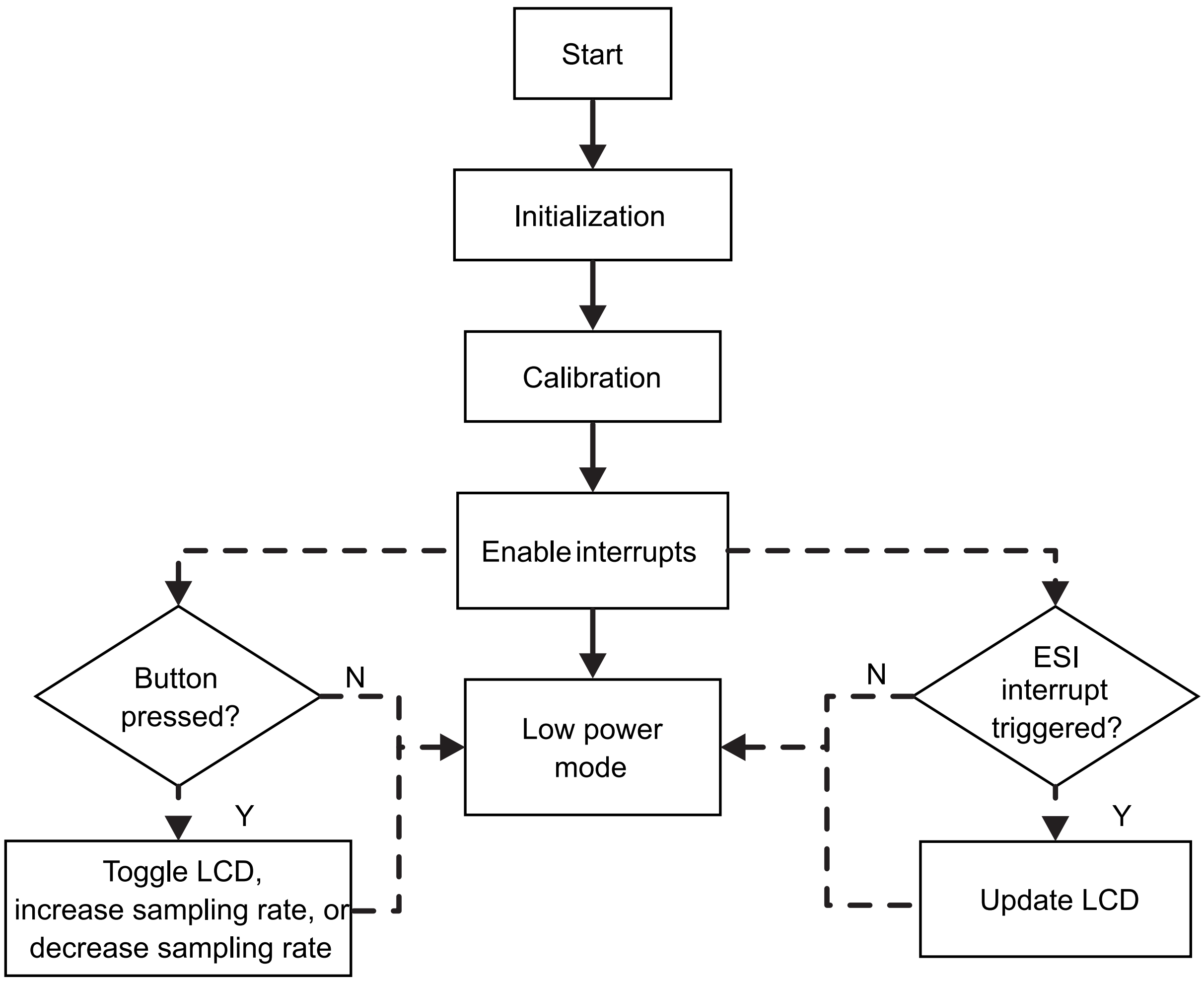


Figure 5. Software Flow

4 Test Setup

The following steps show the testing procedure using the EVM430-FR6989 and Code Composer Studio™ (CCS) version 6.1.

1. Prepare
   (a) Connect the jumpers of the EVM430-FR6989 main board as shown in Figure 6.

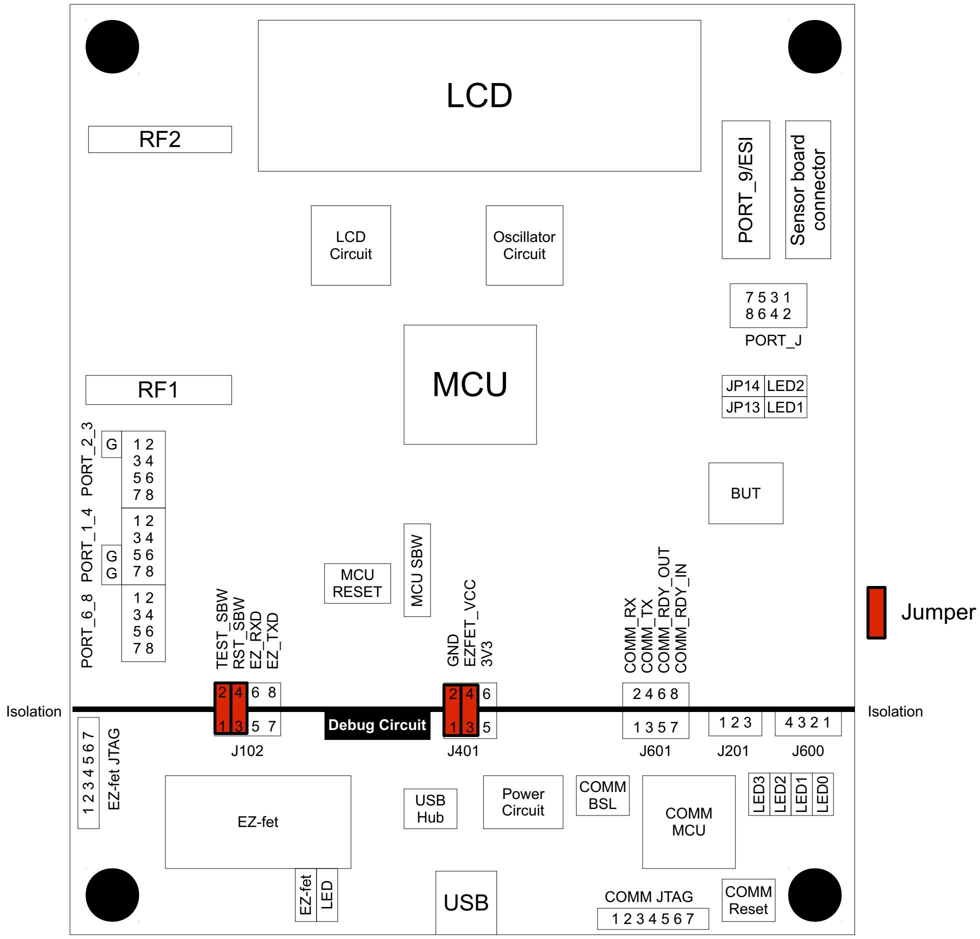


Figure 6. Jumper Setting of Main Board

   (b) Attach the TMR sensor board to the ESI port of the EVM430-FR6989 main board.
   (c) Connect the EVM430-FR6989 main board to the PC with an USB cable.

(d) Glue the split pole magnet on the PCB disc of the motor board of the EVM430-FR6989.

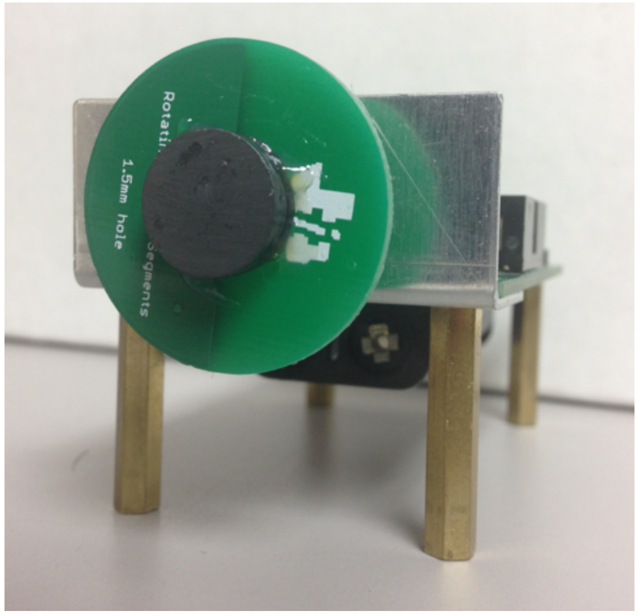


Figure 7. Glue Split Pole Magnet

(e) Place the motor board that the magnet is about 5 mm away from the TMR sensor.

(f) Switch on the motor board.

2. Start the test
   (a) Launch CCS and load the test project.
   (b) Start the debug session of the CCS.
   (c) During calibration, the "8888" is shown on the LCD of the main board.
   (d) Start rotating the magnet by pressing the BUT1 or BUT2 of the motor board.
   (e) After the calibration is completed, the counter number of the ESI is shown on the LCD.
   (f) Press center of the navigation button to toggle off the LCD.
3. During the test
   (a) Press up or down of the navigation button to change the sampling rate of the measurement.
   (b) Pause the debug session of the CCS.
   (c) Start free run mode (Menu → Run → Free Run).
   (d) Observe power consumption with the energy trace function of CCS.
   (e) The total energy consumption and the voltage are recorded for calculating the test results.
4. Repeat Step 3 to test different sampling rates.

5 Test Data

The following shows the test result at different sampling rates. The total energy is obtained by running in free run mode for 10 seconds. The test voltage was measured at 3.27 V. The current is calculated by the following equation.

$$\text{Current consumption} = \text{Energy (mJ)} \div 10\ \text{s} \div 3.27\ \text{V} \quad (1)$$

Table 1. Measuring Result

SAMPLES PER SECOND	ENERGY (mJ)	CURRENT (µA)
99	0.032	0.98
202	0.041	1.25
298	0.049	1.5
420	0.059	1.8
496	0.065	1.99
607	0.074	2.26
780	0.089	2.72
1092	0.115	3.52
1260	0.13	3.97
1489	0.15	4.59
1820	0.178	5.44
2340	0.222	6.79
3277	0.299	9.14
5461	0.47	14.37

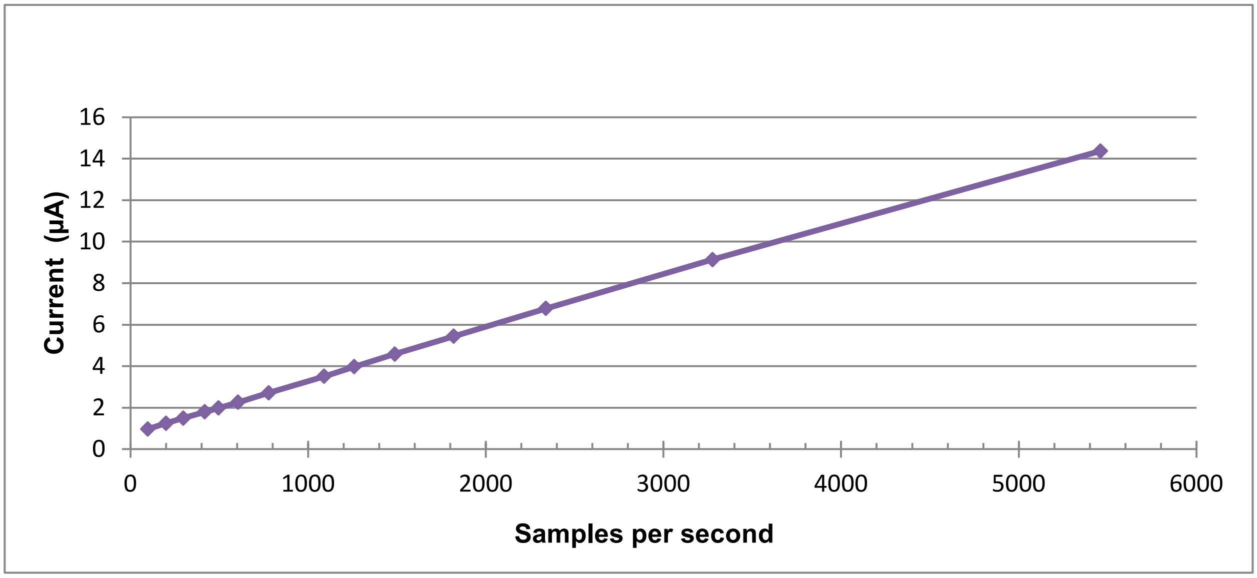


Figure 8. Power Consumption versus Sampling Rate

6 Design Files

6.1 Schematics

To download the schematics, see the design files at TIDM-TMR-WATERMTR.

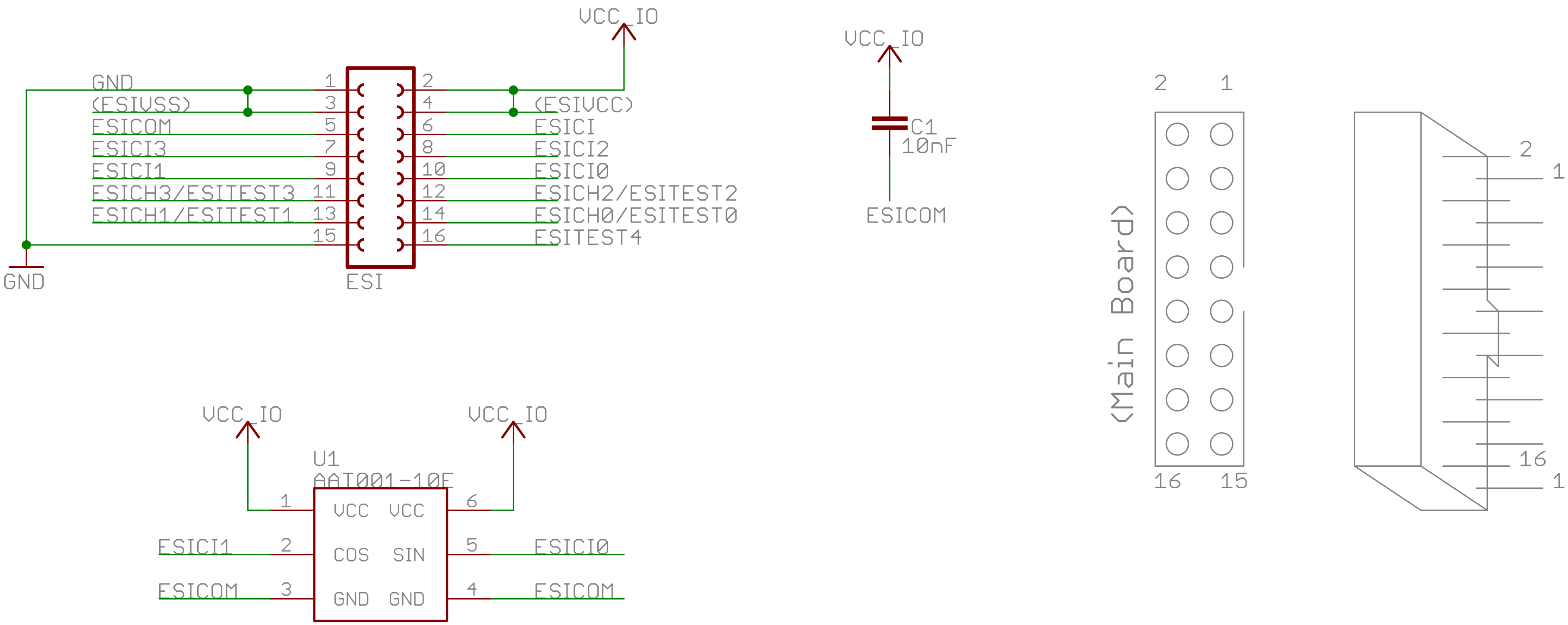


Figure 9. TIDM-TMR-WATERMTR Schematic

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDM-TMR-WATERMTR.

6.3 Layer Plots

To download the layer plots, see the design files at TIDM-TMR-WATERMTR.

6.4 Eagle Design Project

To download the Altium project files, see the design files at TIDM-TMR-WATERMTR.

6.5 Gerber Files

To download the Gerber files, see the design files at TIDM-TMR-WATERMTR.

7 Software Files

To download the software files, see the design files at TIDM-TMR-WATERMTR.

8 References

1. Wikipedia, *Tunnel magnetoresistance* (http://en.wikipedia.org/wiki/Tunnel_magnetoresistance).

9 About the Author

ZACK MAK is a system application engineer at Texas Instruments where he is responsible for developing reference design solutions for the industrial segment. Zack earned his bachelor of electronic and communication engineering from the City University of Hong Kong.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (June 2015) to A Revision	Page
• Changed title from *Low-Power Flow Meter Design Using TMR Sensors* to *Ultra-Low-Power Flow Meter Using TMR Sensors Reference Design for Extended System Longevity*	1

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