Application Report
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An Electronic Water Meter Design Using MSP430F41x

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ABSTRACT

This application report describes how to achieve a reliable and ultra low-power electronic water meter design using the MSP430F41x microcontroller from Texas Instruments. The innovative flow sensor IP and a fault tolerant rotation detection algorithm also are covered.

1 Introduction

The patented flow sensor IP (see reference 3) from Texas Instruments provides a way to detect water flow with no associated mechanical switch. It uses inductors and metal wheel to detect the water flow. This resolves the reliability problem caused by mechanical wear of a switch. Detail structure, hardware and working principle of the flow sensor are described in Section 2.

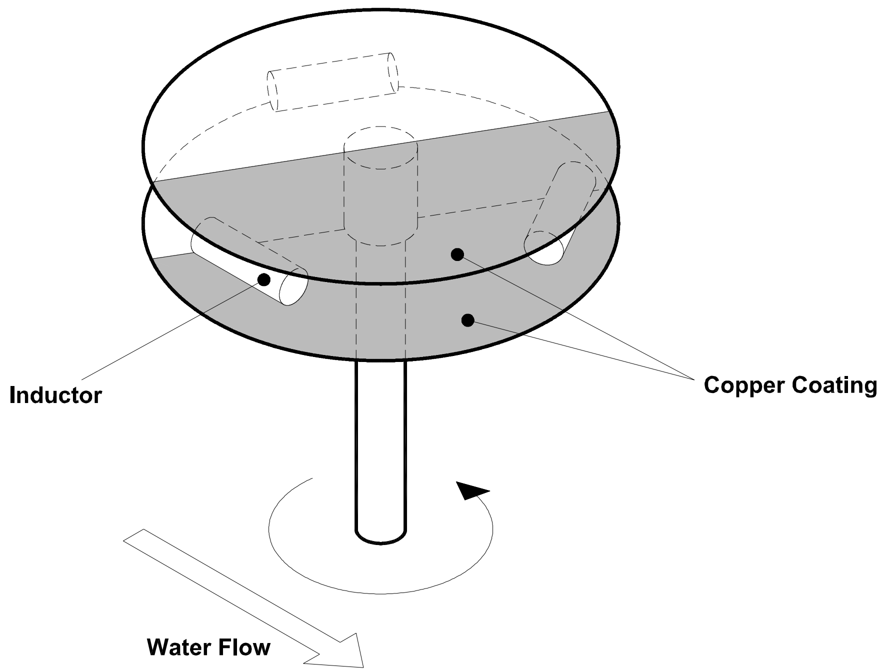
An intelligent rotation detection algorithm is covered in Section 3. This algorithm can tolerate the failure of any one inductive sensor out of the total three. First, the section covers the way to detect different directions of wheel rotation. Then it discusses the handling of a defective sensor.

Section 4 will talk about how to achieve the ultra-low power design. Finally, a summary is given in Section 5. The hardware schematic is included in the appendix A. A software listing based on MSP430F41x can be found on Texas Instruments web site (http://www.ti.com).

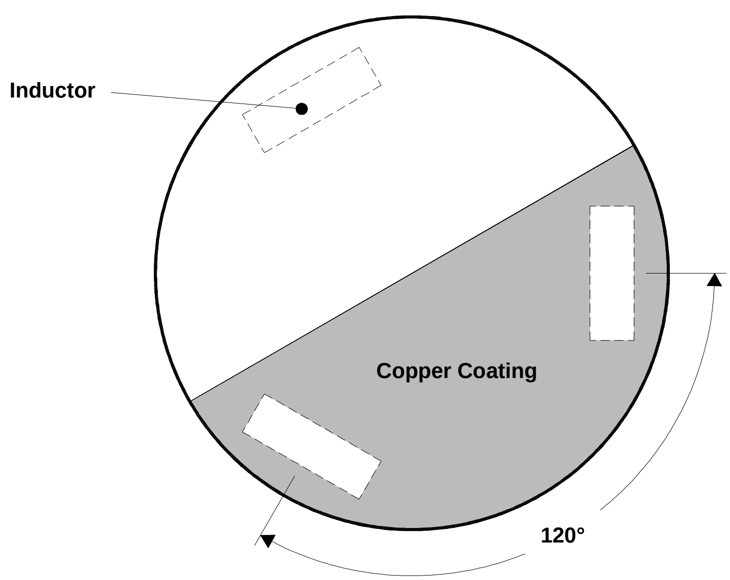
2 Flow Sensor

2.1 Sensor Structure

The mechanical structure of the flow sensor is shown in Figure 1. It consists of two mechanical wheel plates mounted on the same axis and driven by a gear assembly. For simplicity, the gear assembly is not shown on the figure. If there is water flow, the gear assembly drives and rotates the two wheel plates together. The two wheel plates should be made of nonconductive material. Half of the wheel plates is coated with copper or other conductive metal. Between the two wheel plates are three inductors placed with 120 degrees of separation. The rotation of the wheel plates is detected by the three inductor sensors when the copper coating passes over them.



a. Three-Dimensional View



b. Wheel Plate With Copper Coating

Figure 1. Flow Sensor Structure

2.2 Sensor Hardware

Figure 2 shows the schematic for one inductor sensor only. The inductor in the circuit is mounted between two mechanical wheel plates as shown in Figure 1. Each inductor sensor has its own select line. The trigger line is common and the transistor collector outputs for all inductor sensors are tied together.

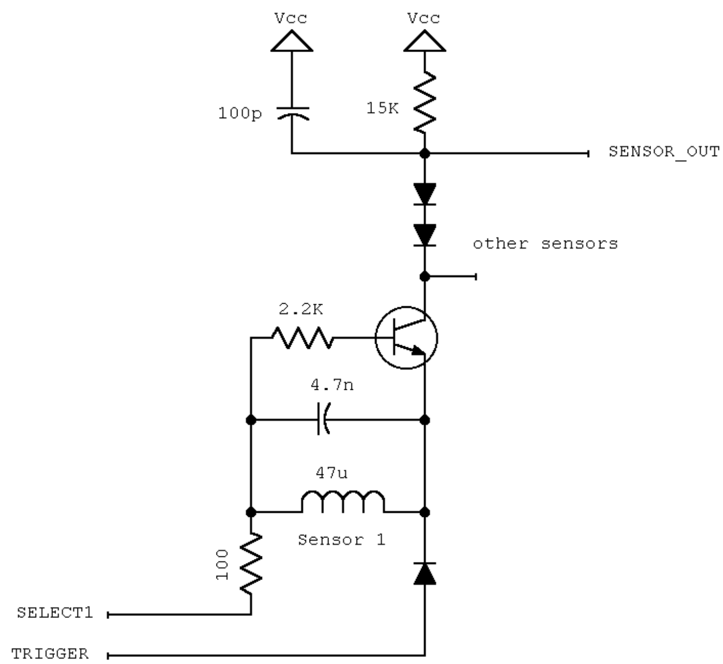
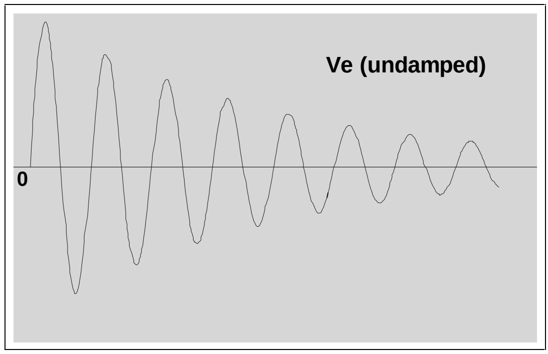
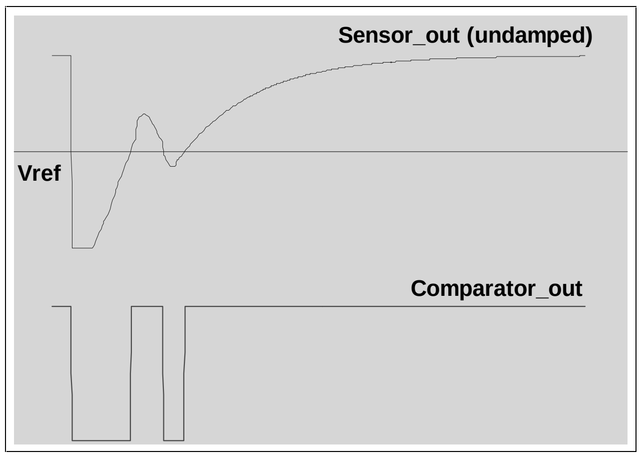


Figure 2. Sensor Schematic Diagram

Driving the corresponding SELECT line low together with a positive pulse on the TRIGGER pin starts an LC oscillation on the selected sensor. Oscillation takes a longer time to die out when the copper coating of the wheel plates is not over the inductor. This is referred to as undamped oscillation. However, if the inductor is covered by the copper coating, the oscillation dies down quickly, as the copper absorbs the energy stored in the inductor. This is referred to as damped oscillation. The oscillation can be observed at the transistor emitter. Both undamped and damped oscillation are shown in Figure 3(a) and Figure 4(a) respectively.

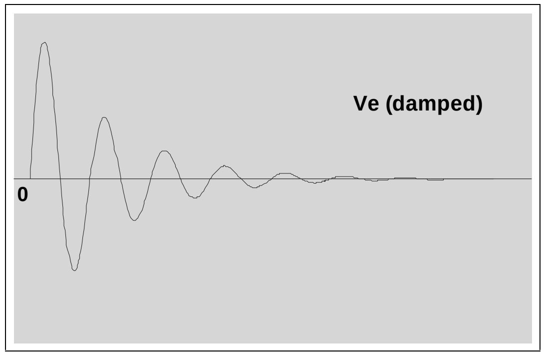


(a) Transistor Emitter Output

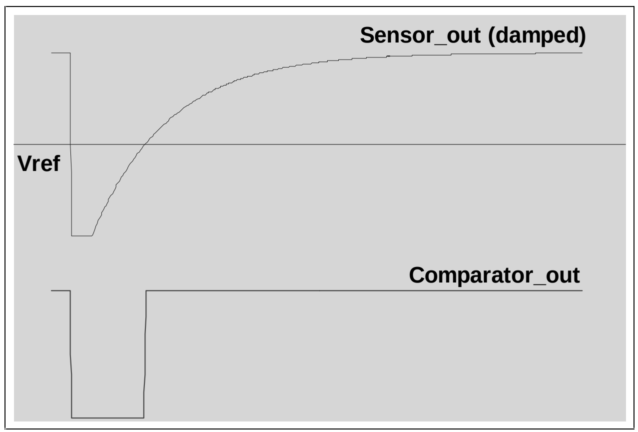


(b) Sensor and Comparator Output

Figure 3. Undamped Oscillation, With No Copper Coating Over the Inductor



(a) Transistor Emitter Output



(b) Sensor and Comparator Output

Figure 4. Damped Oscillation, With Copper Coating Over the Inductor

If the amplitude of the oscillation at the emitter is sufficiently high, the transistor is turned on. Figures 3(b) and 4(b) show the sensor output from the collector of the transistor through two diodes. In damped oscillation, the transistor can be turned on only once by the first big spike in the oscillation. The output is then discharged back to V_{CC} at a rate determined by the RC connected to V_{CC}. For undamped oscillation, transistor can be turned on more than one time as the second or even third spike of the oscillation is sufficiently high. Figure 3(b) shows the sensor output for the undamped oscillation, assuming two triggers on the transistor.

If the inductor sensor output is compared with $V_{ref,}$ which is around 1/2 V_{CC}, the comparator output is as shown in Figure 3(b) and Figure 4(b). There are two rising edges and two falling edges for undamped oscillation, but only one of each for damped oscillation. By checking the number of rising (or falling) edges, we can know whether it is a damped or undamped oscillation. In other words, we can know whether the copper coating is over the inductor or not.

3 Rotation Detection Algorithm

There are different ways to tell whether the wheel plate is rotating, and if so, in which direction. The algorithm shown here is simple, straightforward, and capable of tolerating one defective inductor sensor.

3.1 Rotation With No Defective Sensor

In Figure 5, the copper coating is passing over sensor A. Before the copper coating reaches sensor A, sensor A is in undamped oscillation. Then it switches to damped oscillation when whole of it is covered by the copper coating. The transition from undamped to damped oscillation tells that the copper coating is passing over a sensor.

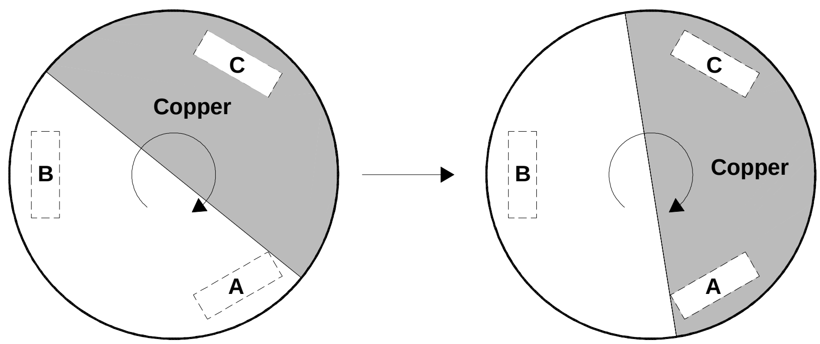


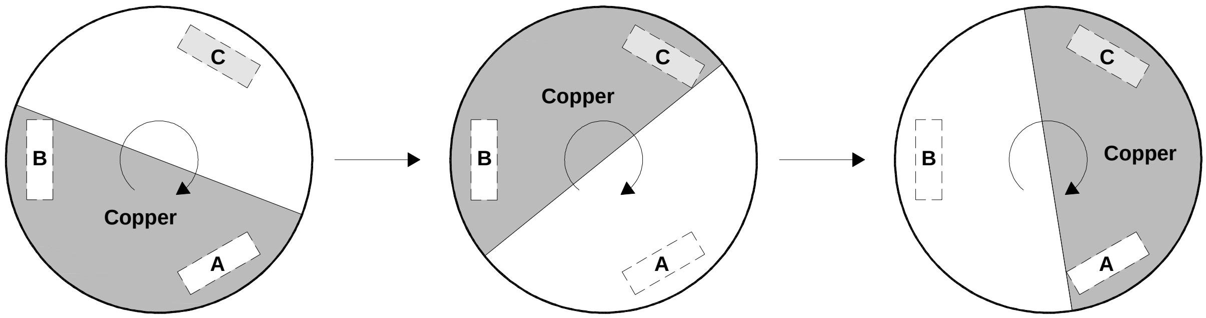
Figure 5. Rotation With No Defective Sensor

Because the three sensors are equally separated by 120 degrees, wheel rotation can be converted to a number of flow counts with each count representing 120 degrees, or three counts representing one revolution. A simple rotation conversion algorithm can be developed. Flow count is incremented or decremented by one when the copper coating passes a sensor. The increment or decrement depends on the direction of rotation. The positive direction can be selected to be either clockwise or counterclockwise, according to user preference.

The direction of rotation can be determined by the sequence of sensors passed by the copper coating. If all three sensors are working, the latest two sensors in the sequence are enough to determine the direction. Assuming sensors A, B, and C are placed in a clockwise direction as in Figure 5, if the last two sensor outputs are from C and A, then rotation is clockwise. However, if they are from B and A, rotation is counterclockwise.

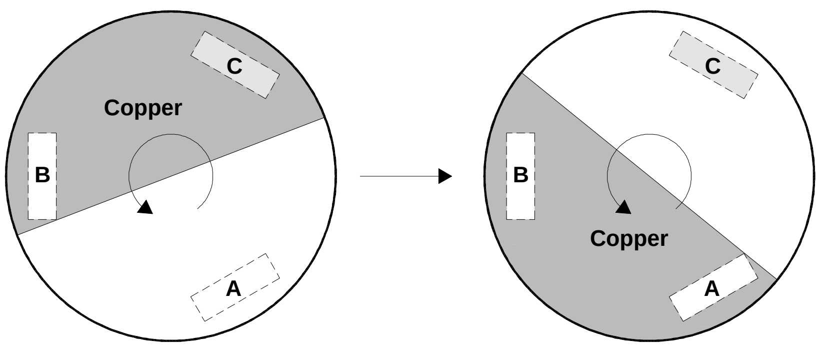
3.2 Rotation With One Defective Sensor

Suppose sensor C has failed. Figure 6 and Figure 7 show two different rotation directions which pass or do not pass the defective sensor C. Because sensor C is defective, the passing sequences are from B to A in both figures. Just considering the sequence from the undamped to the damped oscillation as described in section 3.1 cannot determine the direction of rotation. To make the determination, the algorithm can be extended by having it check the previously passed sensor to see whether it is still covered by the copper coating.



(a) Passing Sensor B (b) Passing Defective Sensor C (c) Passing Sensor A

Figure 6. Rotation Passing Through a Defective Sensor



(a) Passing Sensor B (b) Passing Sensor A

Figure 7. Rotation Not Passing Through the Defective Sensor

Considering Figure 6(c) and Figure 7(b), the copper coating is passing and has covered sensor A. In both cases, the previously passed sensor is sensor B. However, in Figure 6(c), sensor B is not covered by the copper coating, whereas it is covered in Figure 7(b). This difference can be used to distinguish the two rotational directions.

The algorithm can be modified as follows: at the time the copper coating passes over a sensor, if the previously passed sensor is still covered by the copper coating, there will be no interspersed defective sensor and the direction is given by the previously passed sensor. Otherwise, there is an undetected defective sensor between the previous and current sensors. The direction is given by the defective sensor and the rotation distance is doubled.

So for the case in Figure 6, the previous sensor B is not under the copper coating when it passes over sensor A. The direction is determined by the defective sensor C, i.e., from C to A, which is clockwise. The number of flow counts to be incremented or decremented is two. For the case in Figure 7, previous sensor B is under the copper coating, so the direction is determined by the previous sensor B, i.e., from B to A, which is counterclockwise.

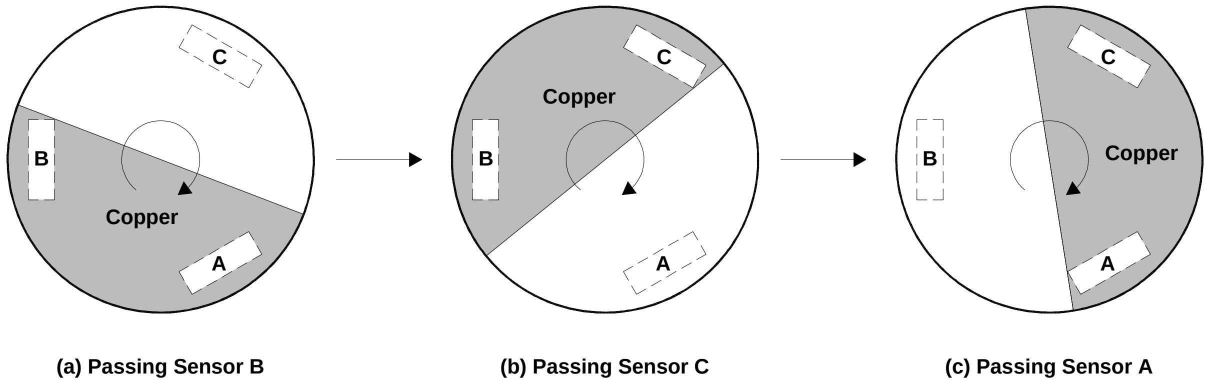


Figure 8. Rotation Through All Sensors With No Defect

The extended algorithm still applies in the case of no defective sensors. Figure 8 shows all the cases for the copper coating passing over each sensor. While the copper coating passes over any sensor, the previous sensor is covered by the copper coating, so that the direction is determined by the previous sensor and the flow count is updated by one.

3.3 Jittering on the Same Sensor

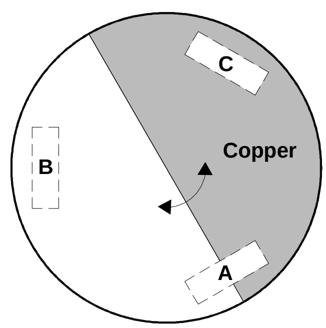


Figure 9. Copper Coating Jittering Around Sensor A

There might be a situation such that the edge of the copper coating stops and stands still or jitters over a particular sensor when there is no water flow. In this case, the sensor completely under the copper coating is always the same one, and no action should be taken. Actually, this situation is same as the case of having two defective sensors. Because of this, two defective sensors are not supported.

4 Ultra-Low Power Design

For water meter application, it is essential to have an ultra-low power design so that a single battery can provide years operation. The sensor hardware discussed on section 2 consumes an extremely low amount of power. For most of the time, the sensor's transistors are completely turned off with no current flown. They are turned on to excite the LC oscillation periodically to detect the wheel plate rotation. To minimize the average current, the frequency and the actual excitation time should be kept to a minimum. However, the actual excitation frequency should not be set so slow as to miss any detection. To better cope with this, two different frequencies can be used. A higher frequency is used when the wheel is rotating. If the wheel stops for a set period of time, it will automatically switch to a lower frequency. When the wheel starts rotating again, it will switch back to the higher frequency immediately.

The selection of the micro-controller is also critical. The MSP430F41x used here is an ultra-low power microcontroller. It takes very few µA in its low-power mode 3 and has extremely fast 6-µs wake-up time. The sensor excitation frequencies with and without rotation are 128 Hz and 8 Hz respectively and the excitation time is only 1µs. With this configuration, an ultra-low power design can be achieved.

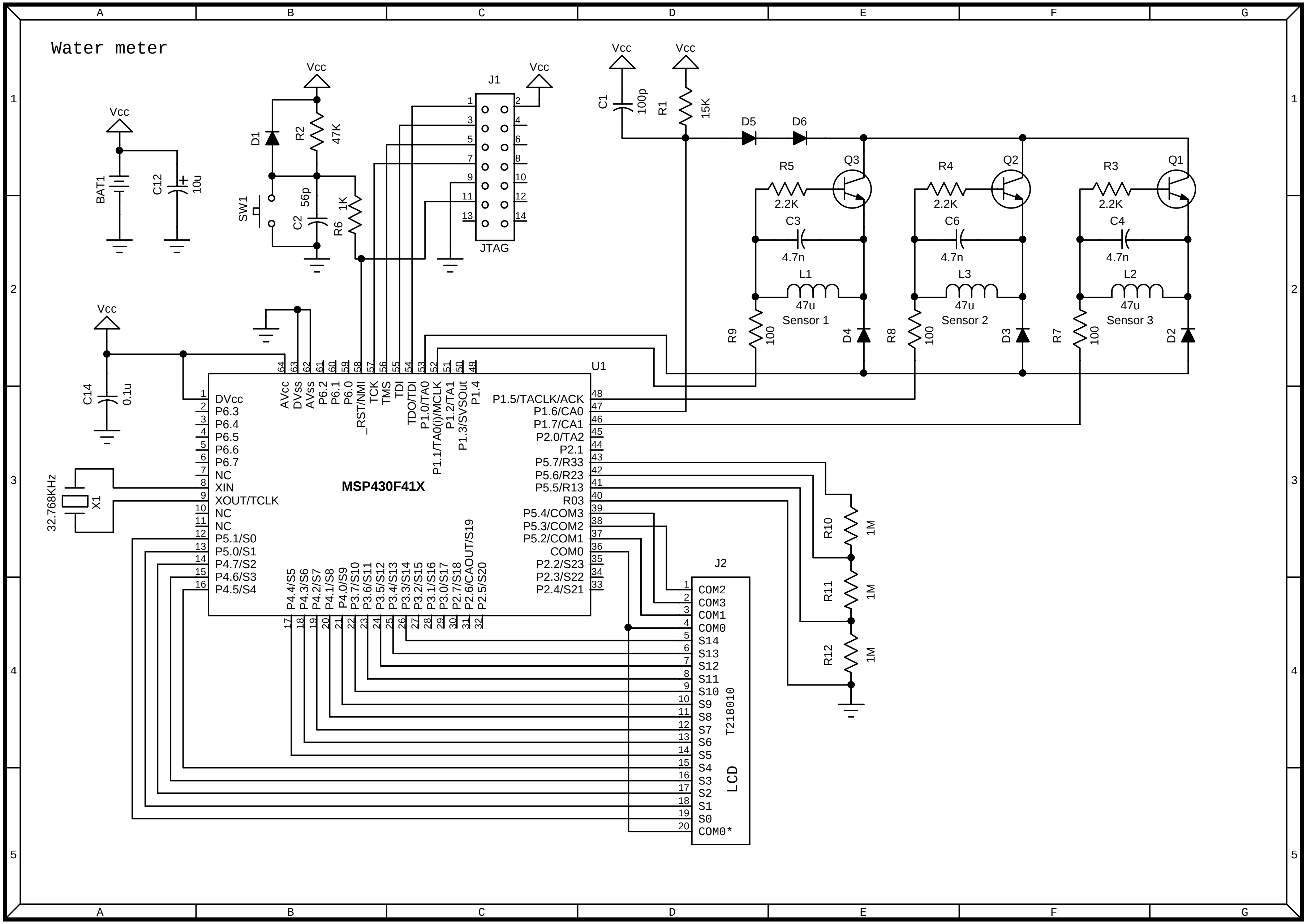
5 Summary

This application report describes an electronic water meter design that uses no mechanical switch and therefore is more durable. The Texas Instruments patented flow sensor IP has been covered in detail. This includes the mechanical structure, sensor hardware and the detection principle of damped and undamped oscillation. A fault-tolerant rotation detection algorithm has been discussed in detail. Different rotation situations, including defective and normal sensors, have been covered. Finally, the design was implemented using an MSP430F41x from Texas Instruments. The working current was found to be as low as 3 µA with no water flow or 16 µA with water flow, making it ideal for water meter application.

6 References

1. *MSP430x4xx Family User's Guide,* Texas Instruments (SLAU056)
2. *MSP430x41x Mixed Signal Microcontroller,* Texas Instruments, data sheet (SLAS340)
3. Patent DE19725806, *"Rotation sensor, e.g. for battery-powered water meter"*

Appendix A. Hardware Schematic


Water meter
A B C D E F G
1 2 3 4 5
Vcc
BAT1
C12 10u
SW1
D1
R2 47K
C2 56p
R6 1K
J1
JTAG
1 2 3 4 5 6 7 8 9 10 11 12 13 14
C1 100p
R1 15K
D5
D6
R5 2.2K
Q3
R4 2.2K
Q2
R3 2.2K
Q1
C3 4.7n
C6 4.7n
C4 4.7n
L1 47u
L3 47u
L2 47u
Sensor 1
Sensor 2
Sensor 3
R9 100
R8 100
R7 100
D4
D3
D2
C14 0.1u
U1
MSP430F41X
DVcc
P6.3
P6.4
P6.5
P6.6
P6.7
NC
XIN
XOUT/TCLK
NC
NC
P5.1/S0
P5.0/S1
P4.7/S2
P4.6/S3
P4.5/S4
AVcc
DVss
AVss
P6.2
P6.1
P6.0
_RST/NMI
TCK
TMS
TDI
TDO/TDI
P1.0/TA0
P1.1/TA0(i)/MCLK
P1.2/TA1
P1.3/SVSOut
P1.4
P1.5/TACLK/ACK
P1.6/CA0
P1.7/CA1
P2.0/TA2
P2.1
P5.7/R33
P5.6/R23
P5.5/R13
R03
P5.4/COM3
P5.3/COM2
P5.2/COM1
COM0
P2.2/S23
P2.3/S22
P2.4/S21
P4.4/S5
P4.3/S6
P4.2/S7
P4.1/S8
P4.0/S9
P3.7/S10
P3.6/S11
P3.5/S12
P3.4/S13
P3.3/S14
P3.2/S15
P3.1/S16
P3.0/S17
P2.7/S18
P2.6/CAOUT/S19
P2.5/S20
32.768KHz
X1
R10 1M
R11 1M
R12 1M
J2
COM2
COM3
COM1
COM0
S14
S13
S12
S11
S10
S9
S8
S7
S6
S5
S4
S3
S2
S1
S0
COM0*
T218010
LCD

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