Application Report

Liquid Concentration Sensing

ABSTRACT

This document describes a system that can sense changes in the concentration of salt in water with TI's ultrasonic solutions. This system comprises a 3D printable tube with two ultrasonic transducers and TI's single-chip ultrasonic sensing solution.

Demo source code and schematics are provided to accelerate the development of a variety of ultrasonic applications. The source files can be downloaded from USSSWLib_Water 02_40_00.

An overview of MSP430™ MCUs and how to enable a variety of end equipments with them can be found at the MSP430™ ultra-low-power sensing & measurement MCUs overview.

For more information on the example code and GUI used in this application report, see *Ultrasonic Sensing Subsystem Reference Design for Water Flow Measurement*. The results presented in this application report are based on the standard example and GUI without modification.

2-MHz Jiakang transducers were found to enable accuracies of ±0.01% and were used throughout the described design process.

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Trademarks

MSP430™ is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

1 Introduction

Current liquid concentration sensors often rely on electrical conductivity or optical properties of the fluid. Conductivity sensors often suffer from electrode degradation while optical or refractory techniques do not work well in dark fluids.

Ultrasonic technology is well suited for liquid concentration sensing because the speed of sound in a tube can give enough resolution to detect small changes in the concentration of a solvent or another fluid. Common applications include salinity and glycol sensors. Ultrasonic technology is preferred over other technologies when information regarding the flow of the fluid is also required.

TI’s ultrasonic sensing technology comprises an ADC-based cross-correlation approach that uses frequency information to determine the ultrasonic time of flight with much higher accuracy than existing TDC based techniques. More about how this unique algorithm works and TI’s ultrasonic sensing subsystem (USS) can be found in TIDM-02005. This solution was found to enable accuracies of ±0.01% when measuring salt concentrations. Further improvements in accuracy are possible by increasing the size of the tube, increasing the excitation voltage, or by increasing the number of excitation pulses.

TI’s ultrasonic sensing subsystem enables a single chip solution that can be connected to ultrasonic transducers along with an op-amp and mux for high-resolution concentration measurements. TI’s USS is integrated with a low-energy accelerator (LEA) and the MSP CPU to enable autonomous low-power operation with an average current consumption of approximately 3 µA (at one measurement per second).

TI's ultrasonic sensing subsystem (see Figure 1-1) comprises a programmable pulse generator (PPG) and a high-speed sigma delta analog to digital converter with a programmable gain amplifier (PGA) that can autonomously excite and capture ultrasonic waveforms for subsequent processing by the integrated LEA.

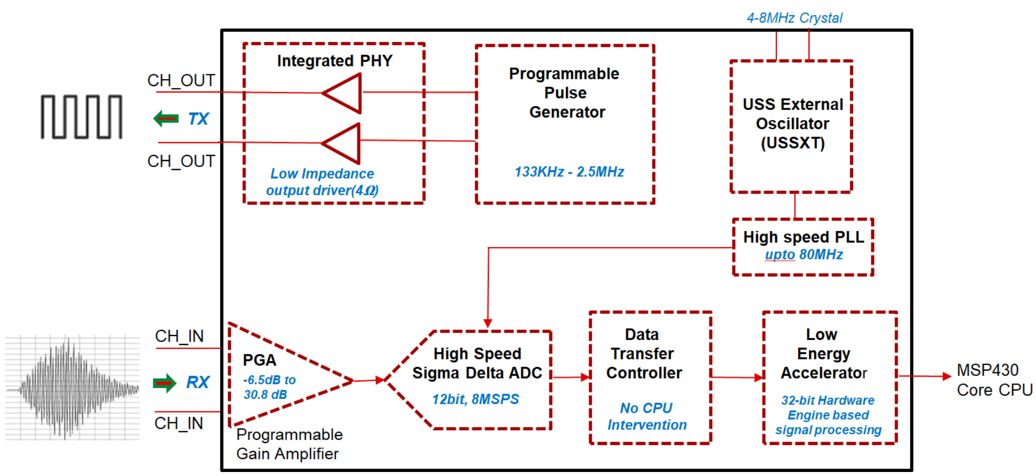

Figure 1-1. TI's Ultrasonic Subsystem

This ultrasonic subsystem first excites the “upstream” transducer connected to CH0_OUT while capturing the waveform from a “downstream” transducer connected to CH0_IN. The ultrasonic subsystem subsequently excites the “downstream” transducer connected to CH1_OUT while capturing the waveform from the “upstream” transducer connected to CH1_IN. These waveforms are then processed by the LEA to determine the difference between the upstream and downstream time of flight.

2 Setup and Configuration

The EVM430-FR6043 is used with two Jiakang 2-MHz transducers in a water configuration as described in TIDM-02005. The testing described here also applies to the EVM430-FR6047. A 3D printed fixture is used to mount the transducers for experimentation (see Figure 2-1). The ultrasonic path between the transducers determines the sensitivity of the tube for concentration sensing. A longer ultrasonic path can enable greater sensitivity at the expense of form factor. The ultrasonic path length used in these experiments was approximately 3 cm.

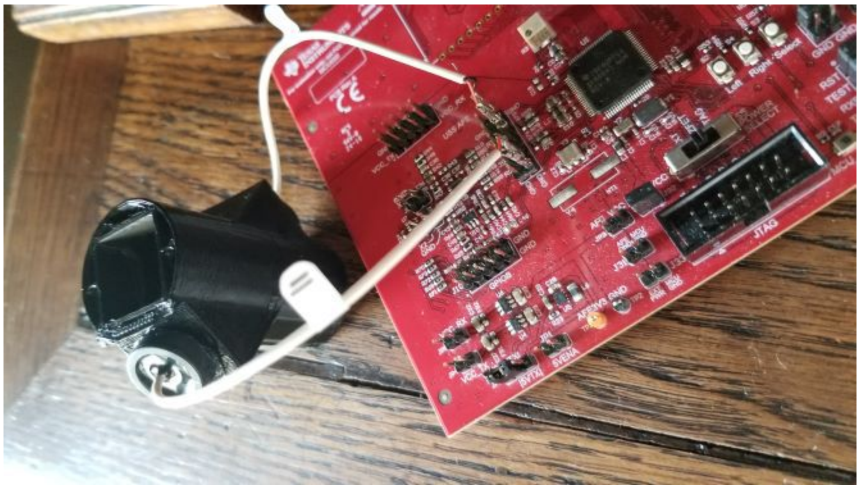

Figure 2-1. 3D Printed Fixture and EVM

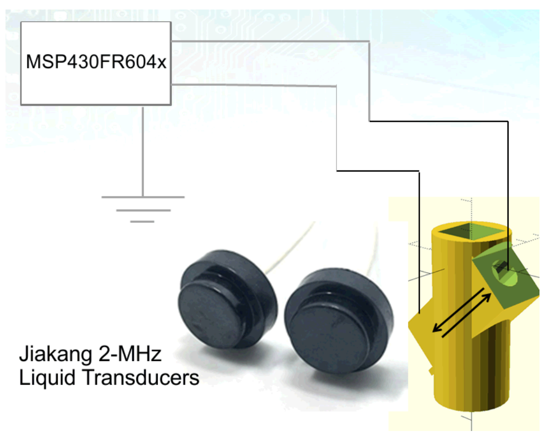

Figure 2-2. Jiakang 2-MHz Ultrasonic Configuration

2.1 EVM GUI Configuration

Figure 2-3 shows the ultrasonic GUI configuration used with this tube. In this configuration, the MSP430FR6043 is configured with 2-MHz excitation and with an 8-MHz signal sampling frequency. Because the assembly of the transducers in a tube can affect their resonance (and optimal excitation frequency), a frequency sweep should be conducted to determine the excitation frequency that gives the highest amplitude response. The Quick Start Guide details the steps for conducting a frequency sweep.

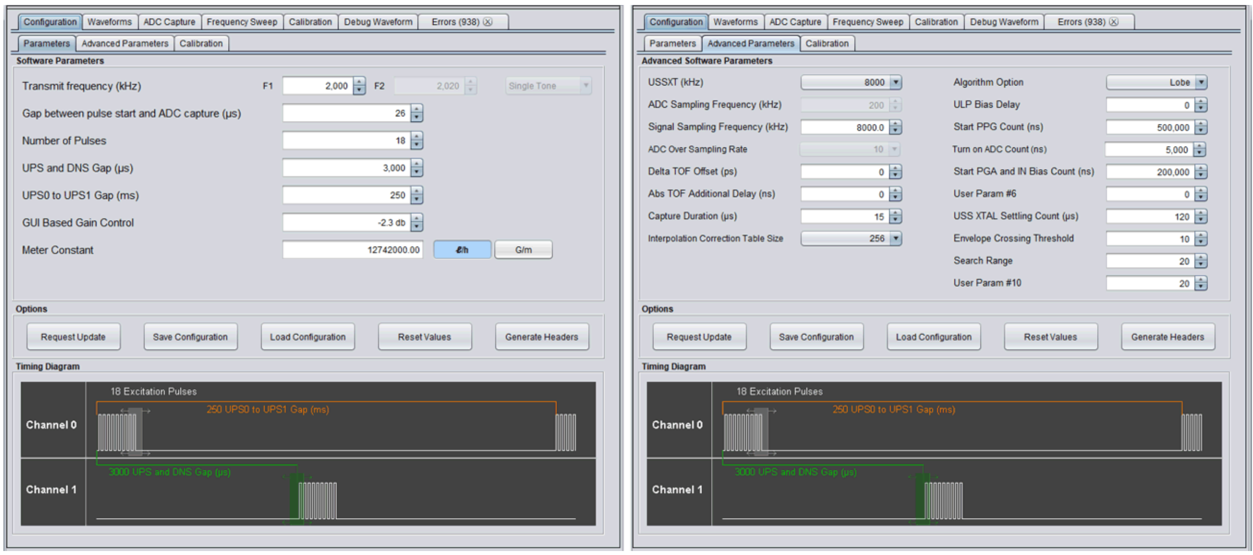

Figure 2-3. GUI Configuration

3 Test Results

The test results in Figure 3-1 show the ADC capture and the change in the absolute time of flight that is seen when the salt concentration within the tube is changed from 2.08% to 1.92% by adding 1 ml of fresh water to a 12-ml solution of 2.08% saline. As can be seen, there is a clear difference in the absolute time of flight for this 0.16% change in concentration. Given the observed standard deviation of 10 ns in absolute time of flight measurements with 10 ns corresponding to a delta of 0.02% in salt concentration, changes of 0.02% in salt concentration can be detected with a single measurement. Averaging over 4 measurements would give an accuracy of 0.01%.

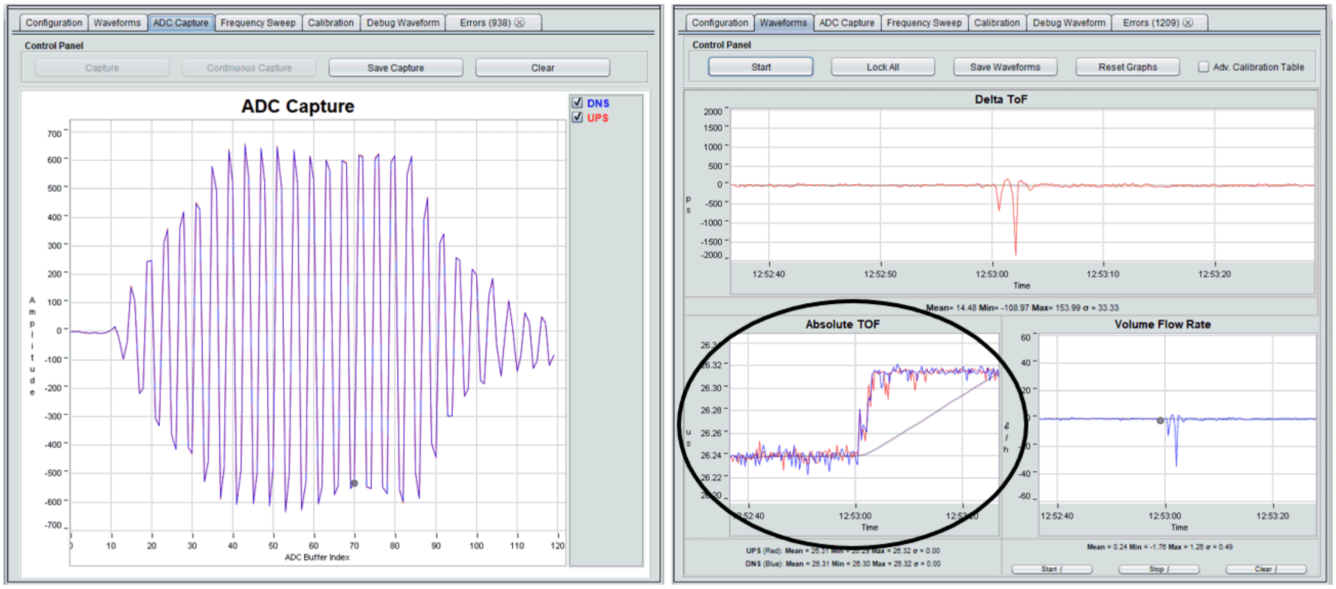

Figure 3-1. Liquid Concentration Sensing Results

4 OpenSCAD 3D Test Fixture

OpenSCAD (http://www.openscad.org/) is a freely available CAD tool that enables parametric generation of 3D models that can be exported for 3D printing. The 3D test fixture that was used in this report follows.

```
PIPE_RADIUS = 13.4;
PIPE_LENGTH = 60;
TRANSDUCER_RADIUS = 5.1;
ULTRASONIC_ANGLE = 135;

difference(){
   union(){
        translate ([0, 0, -10])
        rotate([0, 0, 0])
        cylinder (h = PIPE_LENGTH, r = PIPE_RADIUS);

        translate ([-10, -10, 42])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cube ([20,20,47]);
    }
    union(){
        translate ([-13, -10, 42])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cube ([20,20,5]);

        translate ([23, -10, 10])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cube ([20,20,8]);

        translate ([-8, -8, -8])
        rotate([0, 0, 0])
        cube ([16,16,60]);

        translate ([-30, 0, 46])
        rotate([ULTRASONIC_ANGLE, 0, 90])
        cylinder (h = 150, r = TRANSDUCER_RADIUS);
    }
}
```