Application Report

Ultrasonic Leak Detection

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ABSTRACT

This document describes an ultrasonic leak detection solution. This solution is capable of sensing individual drops of water at very low flow rates.

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

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

2-MHz Jiakang transducers were found to give enough sensitivity to detect individual drops of water in the tube.

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Trademarks

All other trademarks are the property of their respective owners.

1 Introduction

Current leak detectors rely on mechanical impellers and underlying surface sensing. Neither of these technologies is capable of sensing small leaks that might not become detectable until significant water damage to cabinets and floors has already taken place.

Ultrasonic technology is well suited for leak detection because differences in the speed of sound in a water pipe can give enough resolution to detect small leaks that mechanical meters cannot. Utility companies are replacing mechanical water meters with ultrasonic water meters to monetize these small leaks.

TI's ultrasonic sensing technology comprises an analog to digital based cross-correlation approach which uses frequency information to determine the ultrasonic time of flight with much higher accuracy than existing threshold based techniques. More about how this unique algorithm works and TI's ultrasonic sensing subsystem (USS) can be found in TIDM-02005.

TI's ultrasonic sensing subsystem enables a single-chip leak-detection solution that can be connected directly to ultrasonic transducers for high-resolution leak detection measurements. TI's USS is integrated with a low-energy accelerator (LEA) and MSP CPU to enable autonomous low-power operation with an average current consumption of less than 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.

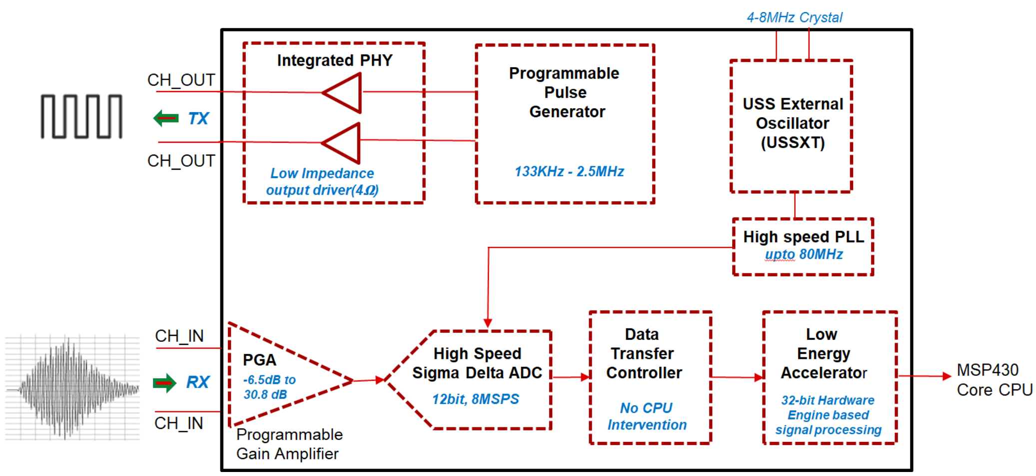

Figure 1-1. TI's Ultrasonic Subsystem

This ultrasonic subsystem (see Figure 1-2) 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.

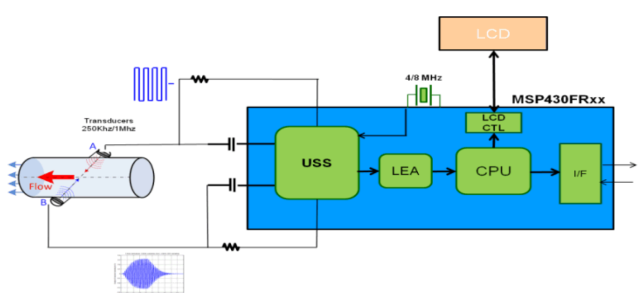

Figure 1-2. Complete Leak Detection System

2 Setup and Configuration

The EVM430-FR6043 is used with two Jiakang 2-MHz transducers. 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). This test fixture comprises three different tubes with a garden hose and enables experimentation with different pipe geometries. The ultrasonic angle and path for the blue tubes were made shorter to make the tubes smaller. The blue tubes exhibited approximately half the sensitivity as the red tube due to this modification. Although this document focuses on the most sensitive tube, the parametric 3D design source enabling smaller form factor tubes is also provided. The 3D printed test fixture is inserted into a cup of water and individual drops of water are released into the submersed tube.

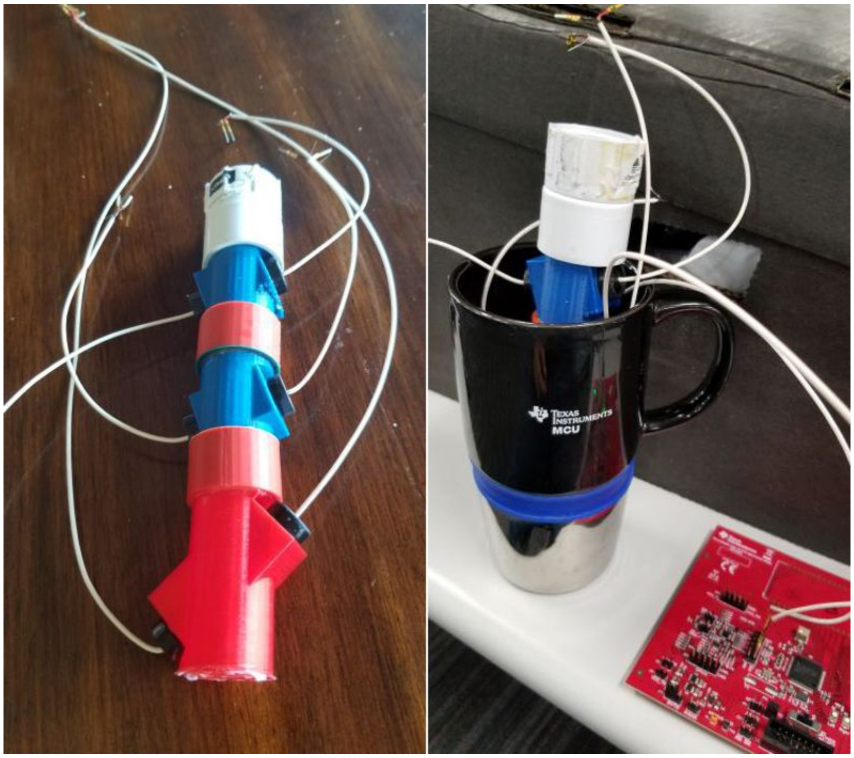

Figure 2-1. 3D Printed Fixture and EVM

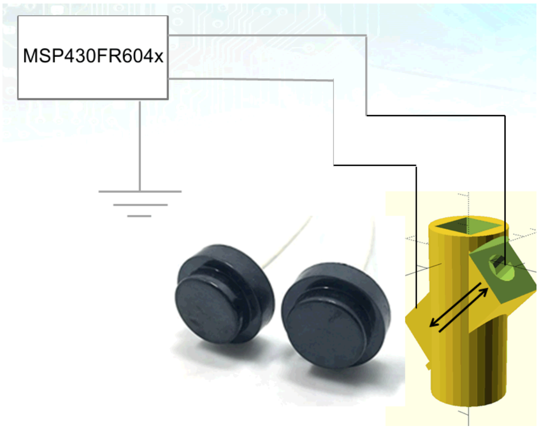

Figure 2-2. Jiakang 2-MHz Ultrasonic Configuration

2.1 EVM430-FR6043 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.

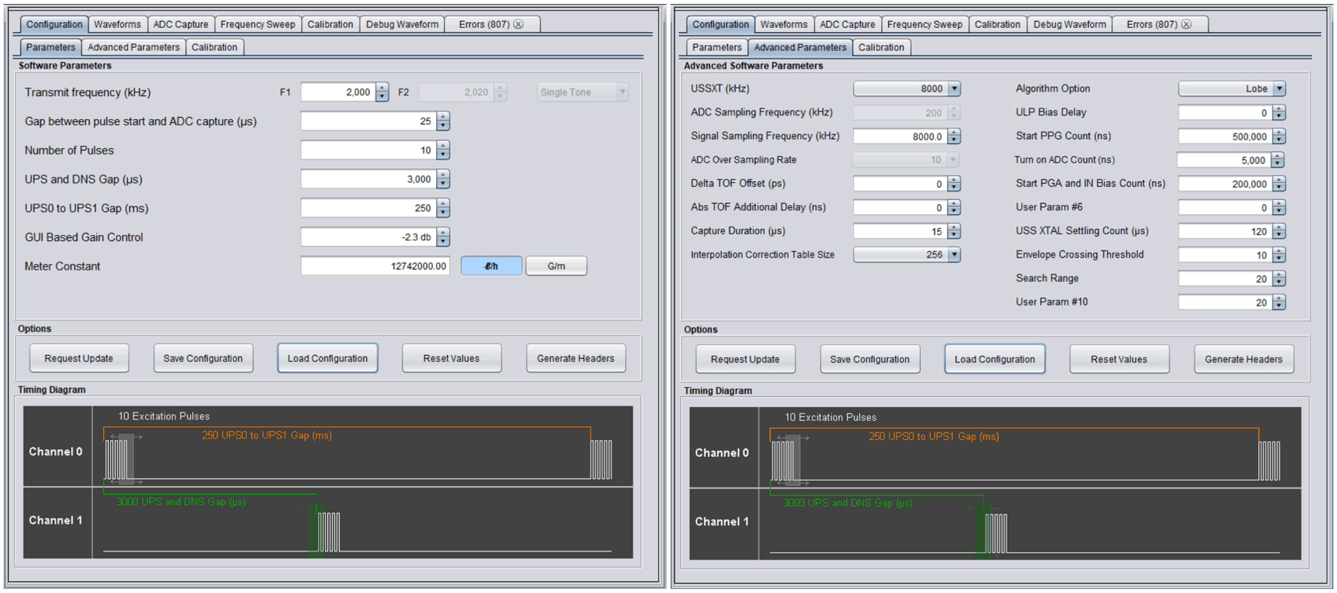

Figure 2-3. EVM430-FR6043 GUI Configuration

3 Test Results

The test results in Figure 3-1 show the captured ADC waveform and the transition that occurs in the delta time of flight when a drop of water is released into the submersed tube. This test was performed at room temperature.

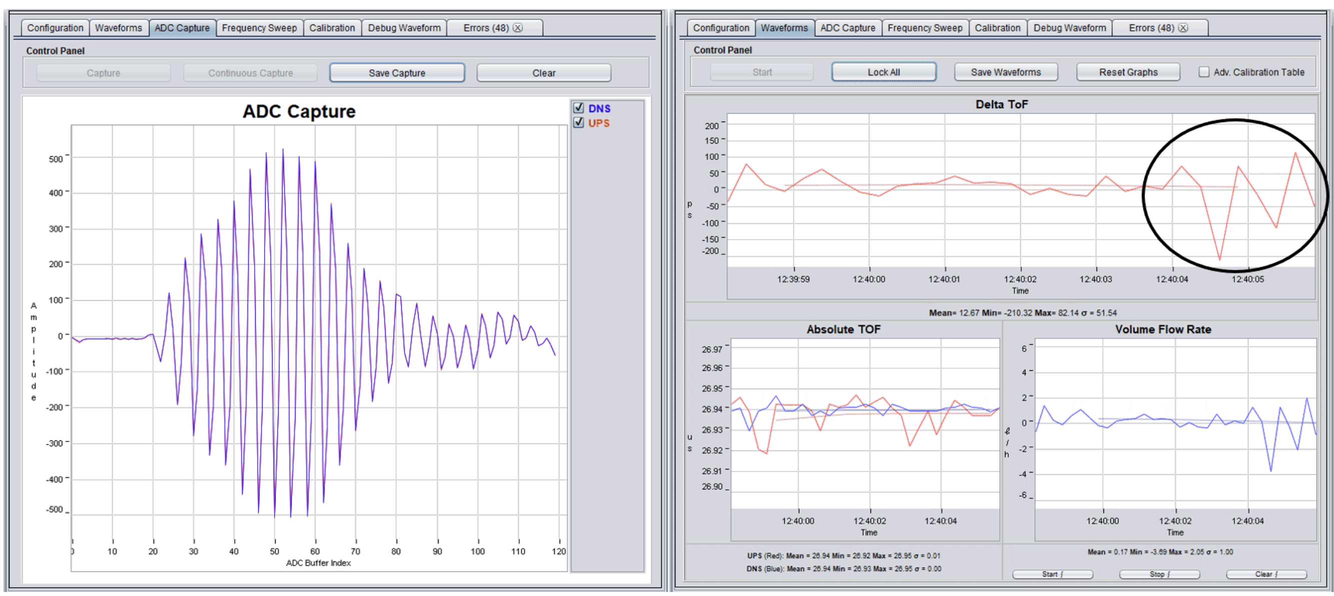

Figure 3-1. ADC Capture and Experimental Results

The oscillations in the delta time of flight seen in the upper right hand corner of Figure 3-1 are due to the liquid movement inside the tube generated by the drop of water.

In a second experiment, the tube is held from the bottom before being filled with water and the pressure on the bottom of the tube is slowly released until water is dripping at approximately 1 drop per second from the bottom of the tube. The delta time of flight in this case goes from a mean of 15 ps to 30 ps as seen in Figure 3-2.

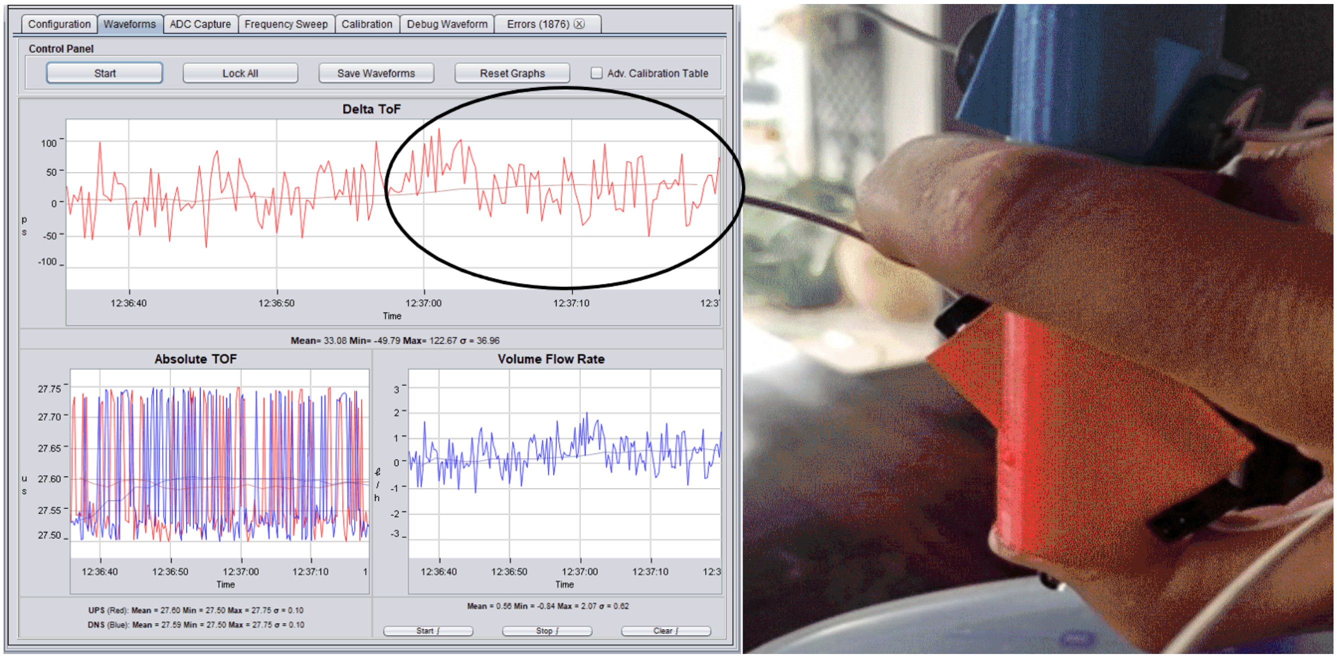

Figure 3-2. One Drop per Second Results

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, -10])
        rotate([0, 0, 0])
        cube ([16,16,60]);

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