Application Report

High-Resolution Anemometers

ABSTRACT

This document describes a high-resolution anemometer based on TI's ultrasonic solutions. This anemometer can sense small changes in air currents sensitive enough to detect doors opening and closing inside a home. This solution can also be used to measure air flow and temperature in HVAC systems.

Demo source code and schematics are provided to accelerate the development of a variety of ultrasonic applications. The source files can be downloaded from USSSW_Lib_Gas. 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 Gas Flow Measurement*. The results presented in this application report are based on the standard example and GUI without modification.

200-kHz Jiakang transducers were found to give enough sensitivity to detect changes in air flow due to doors opening and closing in a home.

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1 Introduction

Current anemometers often rely on mechanical impellers to detect wind velocity. Because of the inertial mass of these impellers, small variations in wind currents (and their direction) can't easily be detected. These devices are also susceptible to freezing rain and snow when installed outside.

Ultrasonic technology is well suited for anemometers because differences in the speed of sound in an open air environment can give enough resolution to detect small changes in speed and direction that impeller based solutions cannot. There are two types of anemometers commonly found in the market, handheld (non-directional) anemometers and outdoor weather stations (two-dimensional) anemometers. One-dimensional anemometers can also be found in applications where the temperature and speed of air flow are of interest such as in HVAC applications.

TI's ultrasonic sensing technology comprises an analog to digital based cross-correlation approach that 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-02003.

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 wind 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 less than 20 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 low energy accelerator (LEA).

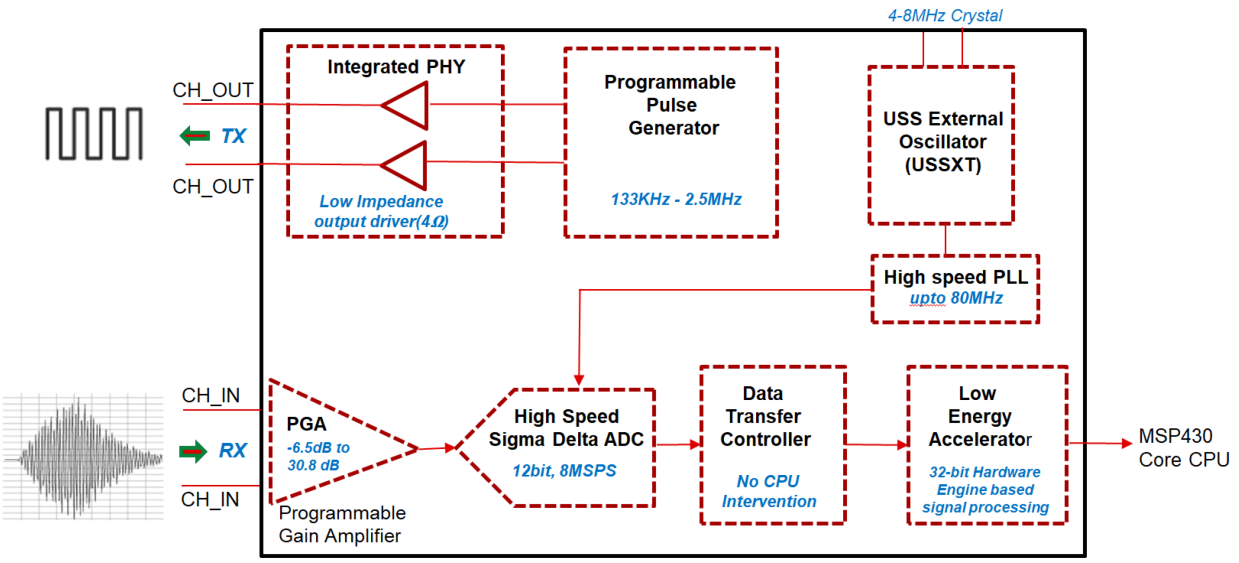

Figure 1-1. TI's Ultrasonic Subsystem

This ultrasonic subsystem (see Figure 1-1) first excites an "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 low energy accelerator to determine the difference between the upstream and downstream time of flight.

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2 Setup and Configuration

The EVM430-FR6043 is used with four Jiakang 200-kHz transducers. A 3D printed fixture is used to mount the transducers for experimentation. This test fixture comprises a transducer mount that is connected to a reflecting plate that enables ultrasonic waves to be transmitted and received between two separate transducer pairs (see Figure 2-1).

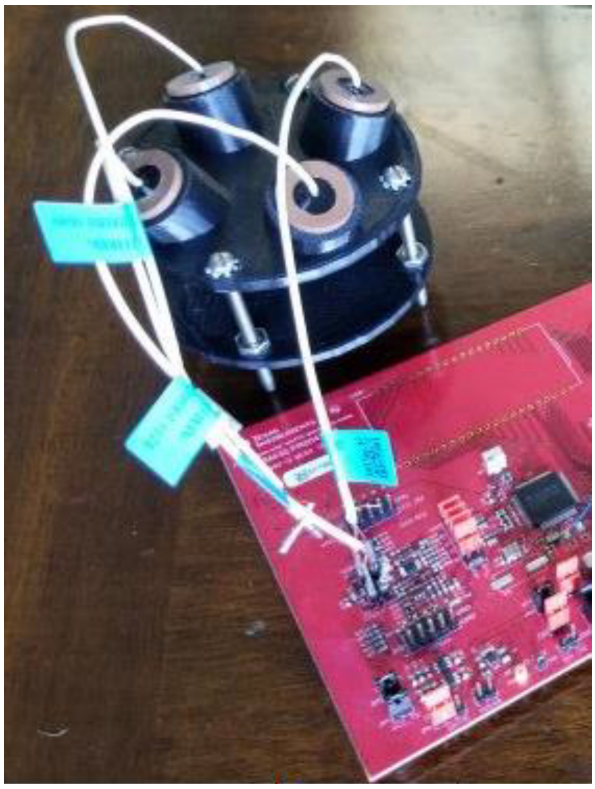

Figure 2-1. 3D Printed Fixture and EVM

The system diagram in Figure 2-2 shows an additional mux (the TMUX1209) that is required when implementing a 2-dimensional (or greater) anemometer. This mux is not required when implementing a 1-dimensional anemometer because only one pair of transducers is required for this case.

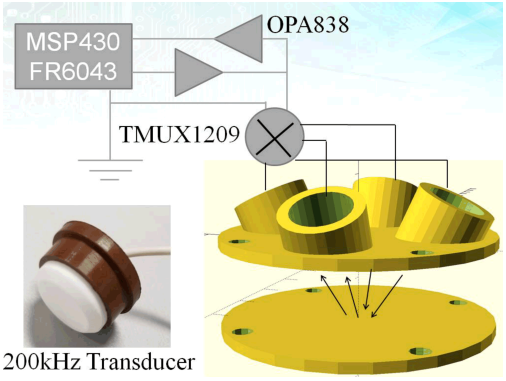

Figure 2-2. Jiakang 200-kHz Ultrasonic Configuration

The TMUX1209 can support up to four pairs of transducers to enable 3-dimensional air flow sensing for air born applications. Figure 2-3 shows the TMUX1209 block diagram, and Figure 2-4 shows the connections. The two channels of the TMUX1209 (DA and DB) are connected to the two transducer connectors (J5.1 and J6.1 of the

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EVM schematics). S1A and S1B are connected to each transducer in one pair while S2A and S2B are connected to each transducer in the second pair. A software-controlled GPIO from the MSP430FR6043 is connected to pin A0 of the TMUX1209 to take alternating measurements between the two transducer pairs. The A1 pin should be connected to GND with EN connected to VCC.

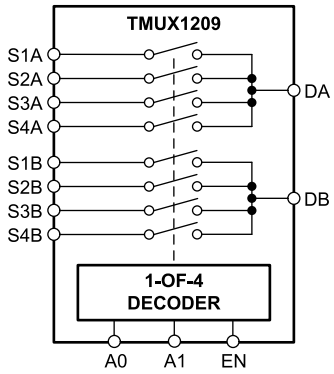

Figure 2-3. TMUX1209 Block Diagram

Figure 2-4 shows a modified version of the TIDM-02003 schematics in which the TMUX1209 has been connected to the transducer connections.

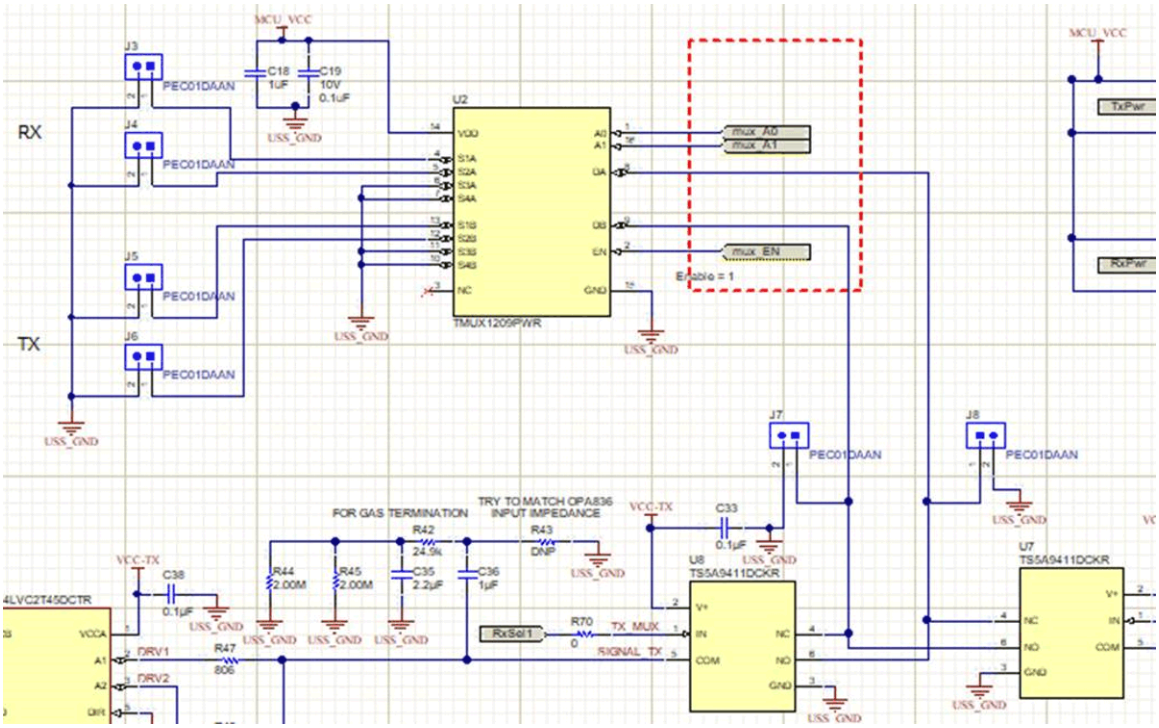

Figure 2-4. Schematic

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2.1 EVM430-FR6043 GUI Configuration

Figure 2-5 shows the ultrasonic GUI configuration used with this anemometer. In this configuration, the MSP430FR6043 is configured with a 200-kHz frequency sweep and with 1-MHz signal sampling frequency. A frequency sweep was first conducted to determine the excitation band giving the highest amplitude response for these transducers to determine the F1 and F2 parameters.

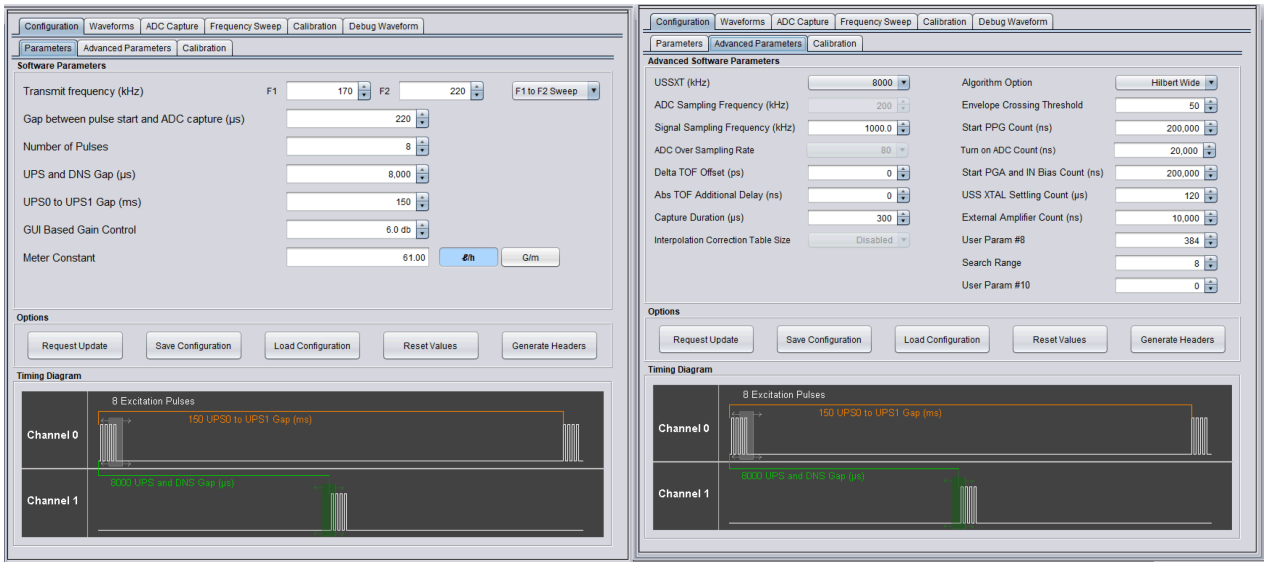

Figure 2-5. EVM430-FR6043 GUI Configuration

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 door is open in the room with the test fixture. The change in air temperature during this event can also be seeing in the absolute time of flight. This test was performed at room temperature.

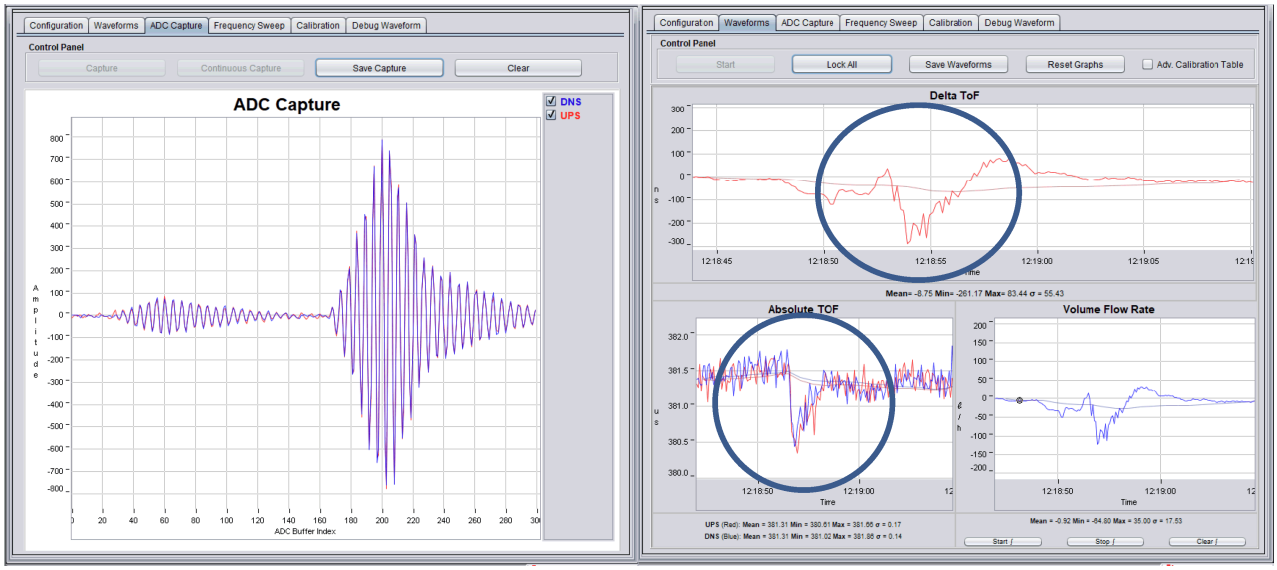

Figure 3-1. ADC Capture and Experimental Results

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4 OpenSCAD 3D Test Fixture

OpenSCAD is a freely available CAD tool that enables parametric generation of 3D models that can be exported for 3D printing. The parametric 3D test fixture used in this paper appears below. Modifications to the ULTRASONIC_ANGLE can be made to enable smaller form factor (or more sensitive) devices.

```
TRANSDUCER_RADIUS=8.25;
HOLE_RADIUS=3;
LID_RADIUS=40;
LID_LENGTH=3;
CYLINDER_LENGTH=20;
ULTRASONIC_ANGLE=25;
difference(){
    union(){
    translate ([0, 0, 0])
    rotate([0, 0, 0])
    cylinder (h = LID_LENGTH, r = LID_RADIUS);

    translate ([0, 0, -25])
        rotate([0, 0, 0])
        cylinder (h = LID_LENGTH, r = LID_RADIUS);

        translate ([0, -20, -5])
        rotate([ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH, r = TRANSDUCER_RADIUS+3);

        translate ([0, 20, -5])
        rotate([-ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH, r = TRANSDUCER_RADIUS+3);

        translate ([20, 0, -5])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cylinder (h = CYLINDER_LENGTH, r = TRANSDUCER_RADIUS+3);

        translate ([-20, 0, -5])
        rotate([0, -ULTRASONIC_ANGLE, 0])
        cylinder (h = CYLINDER_LENGTH, r = TRANSDUCER_RADIUS+3);
    }
    union(){
        translate ([0, 0, -20])
        rotate([0, 0, 0])
        cylinder (h = 20, r = LID_RADIUS);

        translate ([0, -20, -5])
        rotate([ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);

        translate ([0, 20, -5])
        rotate([-ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);

        translate ([20, 0, -5])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);

        translate ([-20, 0, -5])
        rotate([0, -ULTRASONIC_ANGLE, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);


        translate ([25, 25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);

        translate ([-25, -25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);

        translate ([-25, 25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);

        translate ([25, -25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);
```


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```
          }
    }
          TRANSDUCER_RADIUS=8.25;
HOLE_RADIUS=3;
LID_RADIUS=40;
LID_LENGTH=3;
CYLINDER_LENGTH=20;
ULTRASONIC_ANGLE=25;
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    union(){
    translate ([0, 0, 0])
    rotate([0, 0, 0])
    cylinder (h = LID_LENGTH, r = LID_RADIUS);

    translate ([0, 0, -25])
        rotate([0, 0, 0])
        cylinder (h = LID_LENGTH, r = LID_RADIUS);

        translate ([0, -20, -5])
        rotate([ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH, r = TRANSDUCER_RADIUS+3);

        translate ([0, 20, -5])
        rotate([-ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH, r = TRANSDUCER_RADIUS+3);

        translate ([20, 0, -5])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cylinder (h = CYLINDER_LENGTH, r = TRANSDUCER_RADIUS+3);

        translate ([-20, 0, -5])
        rotate([0, -ULTRASONIC_ANGLE, 0])
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        translate ([0, 0, -20])
        rotate([0, 0, 0])
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        translate ([0, -20, -5])
        rotate([ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);

        translate ([0, 20, -5])
        rotate([-ULTRASONIC_ANGLE, 0, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);

        translate ([20, 0, -5])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);

        translate ([-20, 0, -5])
        rotate([0, -ULTRASONIC_ANGLE, 0])
        cylinder (h = CYLINDER_LENGTH+1, r = TRANSDUCER_RADIUS);


        translate ([25, 25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);

        translate ([-25, -25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);

        translate ([-25, 25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);

        translate ([25, -25, -30])
        rotate([0, 0, 0])
        cylinder (h = 50, r = 3);
         }
    }
```


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