

# Application Report

## Ultrasonic Surface Sensing



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MSP430 Applications

### ABSTRACT

This document describes a high-resolution ultrasonic level sensing solution. The 3D test fixture may also be used for volumetric temperature or gas concentration sensing applications.

Demo source code and schematics are provided to accelerate the development of ultrasonic sensing applications. The files can be downloaded from [USSSWLib\\_Gas 02\\_30\\_00\\_03](#).

For more information on the example code and GUI used in this application report, see [Ultrasonic Sensing Subsystem Reference Design for Gas Flow Measurement](#). This application report uses the standard example and GUI without modification.

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## 1 Introduction

Current surface sensors often rely on contact with a surface to determine if some condition requiring maintenance has occurred. Some examples include determining the amount of wear on a brake's surface, structural monitoring, and determining the amount of material in a machine.

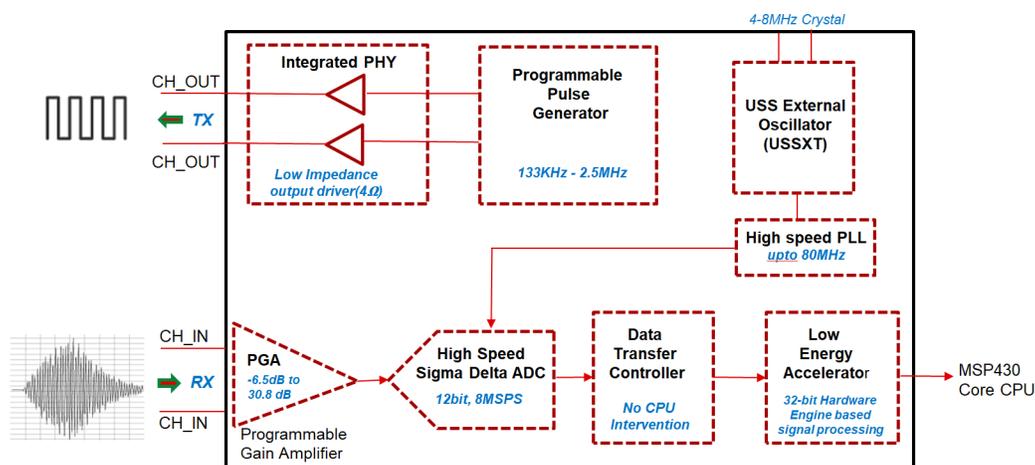
Brake monitors commonly use a contacting piece of metal that makes an audible noise when the brake pad needs replacement. Contactless sensing of this wear enables predictive maintenance that can minimize down time for manufacturing robots, fleet vehicles, and elevators. Structural monitoring of bridges and buildings can be critical to detecting problems that might be aggravated during high winds and earthquakes. Identifying low-frequency oscillations in these structures early on can be critical to avoiding future catastrophic failures. Machine material monitoring applications include paper counting for 2D printers, spool sensing for 3D printers, and production line profile scanning. Contactless sensing of surfaces in these applications is often preferred to enable maintenance to be conducted to minimize down time.

Ultrasonic technology is well suited for contactless surface and structural sensing because it does not require embedding a sensor in the material of interest. Bridges and industrial buildings are often exposed to corrosive chemicals that limit the lifetime of embedded sensors. Braking systems often operate at higher temperatures that can render embedded sensors useless.

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-02005](#).

TI's ultrasonic sensing subsystem enables a single-chip surface or structural sensing solution that can be connected directly to an ultrasonic transducer for high-resolution 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 20  $\mu$ A (at one measurement per second).

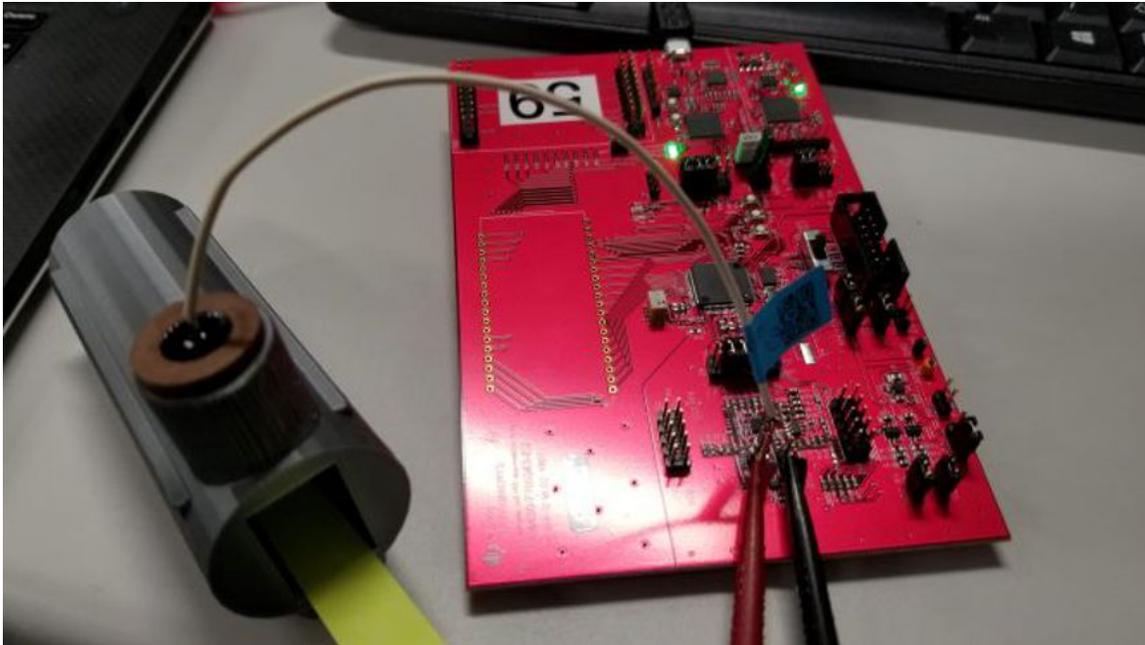
TI's ultrasonic sensing subsystem (see [Figure 1-1](#)) comprises a programmable pulse generator (PPG) and a high speed sigma-delta analog-to-digital converter (ADC) with a programmable gain amplifier (PGA) that can autonomously excite and capture ultrasonic waveforms for subsequent processing by the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



**Figure 1-1. TI's Ultrasonic Subsystem**

## 2 Setup

The EVM430-FR6043 is used with a single Jiakang 200-kHz transducer. A 3D printed fixture is used to mount the transducer for experimentation. A piece of paper is inserted and removed from the fixture to demonstrate the sensitivity of the system.



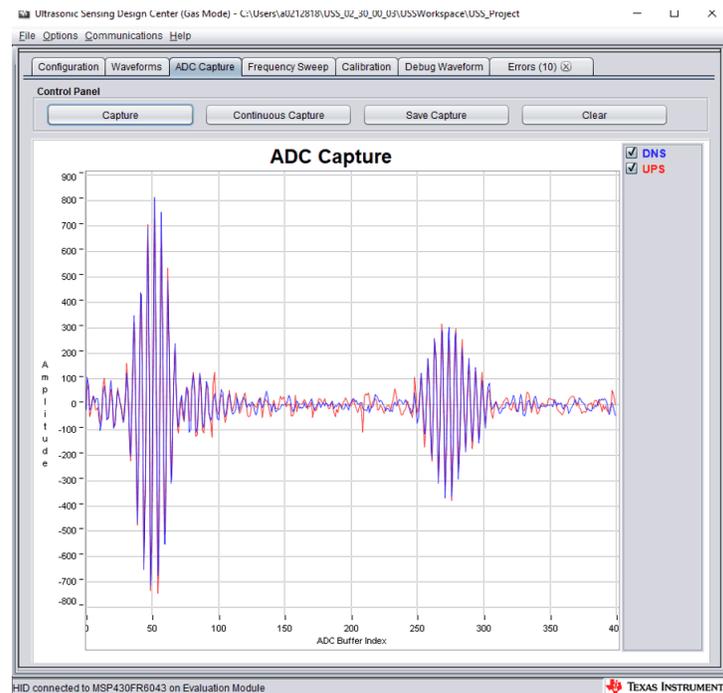
**Figure 2-1. 3D Printed Fixture and EVM**



**Figure 2-2. Jiakang 200-kHz Transducer**

## 2.1 Transducer Placement

To obtain the proper signal levels, the transducer should be placed close to the surface that is being sensed. The maximum distance that can be sensed with these transducers was found to be approximately 20 cm. Because some applications may be constrained with regards to space and initial excitation noise that can affect the first reflection, the second (or third) reflection might give better (and more accurate) results. Accuracy in temperature and gas concentration sensing applications can also be improved by increasing the distance between the transducer and the reflecting surface.



**Figure 2-3. First and Second Ultrasonic Reflections**

## 2.2 EVM430-FR6043 Configuration

The EVM430-FR6043 is used in the standard gas meter configuration with one transducer connected to J8 and both transducer connections connected together. The Design Center GUI is used to configure the MSP430FR6043 and capture data.

Design Center configuration used for testing can be seen in [Figure 2-4](#).

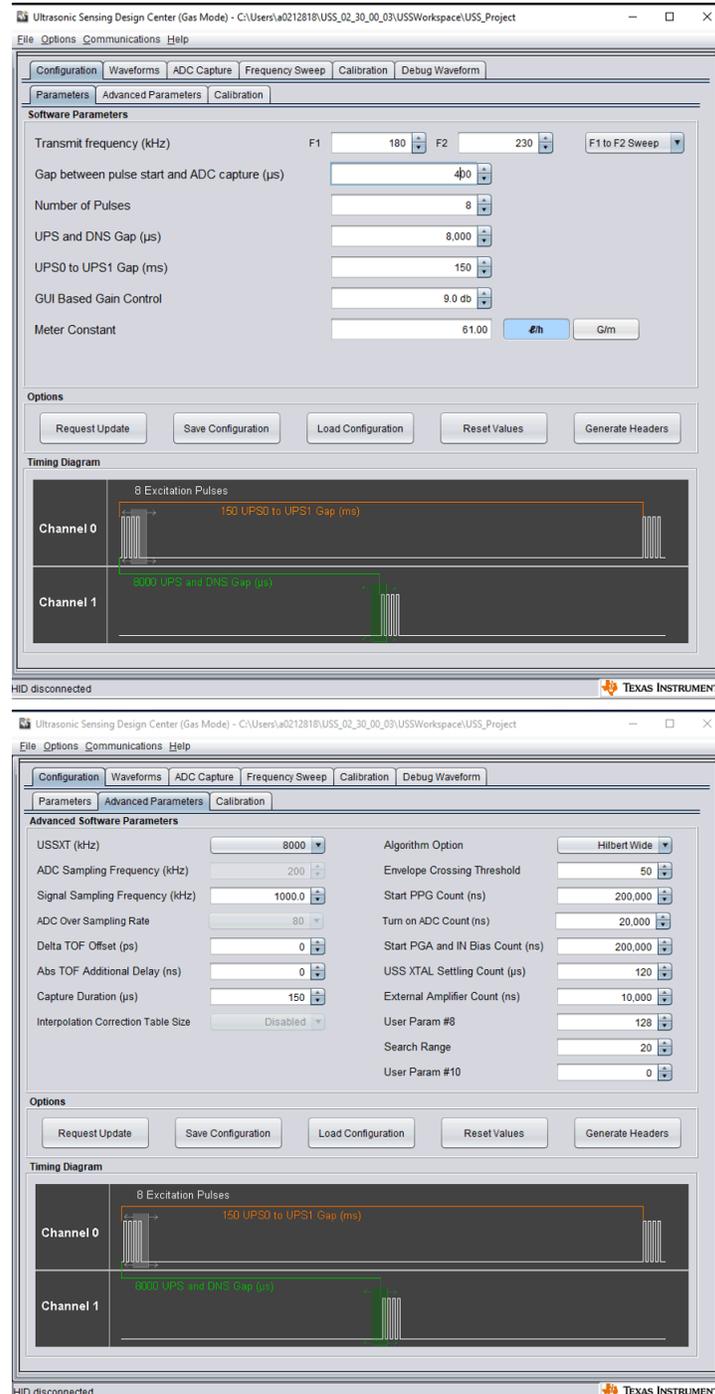


Figure 2-4. Design Center Configuration

### 3 Test Results

Figure 3-1 shows the captured ADC signal with the test fixture and configuration shown in Section 2. This test was performed at room temperature.

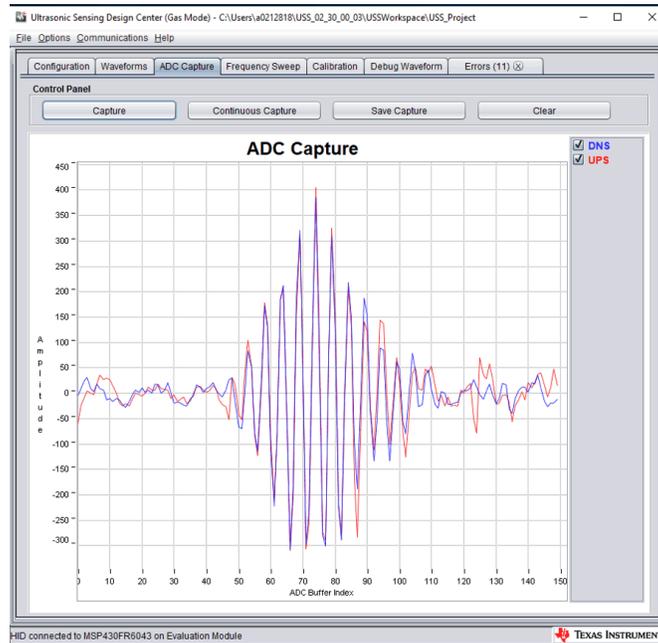


Figure 3-1. ADC Capture

Figure 3-2 shows that there was a change of approximately 4  $\mu\text{s}$  in the absolute time of flight after removing the piece of paper from the 3D test fixture. During the movement of the piece of paper, a transition between the upstream and downstream signals is also shown. The test setup described in this paper can sense changes in the absolute time of flight of less than 50 ns (0.01%).



Figure 3-2. Level-Sensing Test Results

As can be seen through this simple experiment, the MSP430FR6043 enables best-in-class surface sensing at a fraction of the cost and hardware required by other solutions.

## 4 OpenSCAD 3D Test Fixture

OpenSCAD (<http://www.openscad.org/>) is a freely available CAD tool that enables parametric generation of 3D models and can export those models for 3D printing. The 3D test fixture used in this paper follows.

```

TRANSDUCER_RADIUS=8.25;
PIPE_RADIUS=17;
PIPE_LENGTH=95;
CHANNEL_WIDTH=15;
CHANNEL_HEIGHT=24;
ULTRASONIC_ANGLE=90;
ULTRASONIC_LENGTH=60;

union(){
difference(){

    union(){

        translate ([0, 0, -25])
        rotate([0, 0, 0])
        cylinder (h = PIPE_LENGTH, r = PIPE_RADIUS);

        translate ([-(PIPE_RADIUS+9), .1, -13])
        rotate([0, ULTRASONIC_ANGLE, 0])
        cylinder (h = ULTRASONIC_LENGTH, r = TRANSDUCER_RADIUS+2);

    }

union(){
    translate ([-(CHANNEL_HEIGHT/2), -CHANNEL_WIDTH/2, -25])
    rotate([0, 0, 0])
    cube ([CHANNEL_HEIGHT,CHANNEL_WIDTH,PIPE_LENGTH]);

    translate ([-(PIPE_RADIUS+9), 0, -13])
    rotate([0, ULTRASONIC_ANGLE, 0])
    cylinder (h = 150, r = TRANSDUCER_RADIUS);

}

}

union(){
    translate ([-(CHANNEL_HEIGHT/2), -CHANNEL_WIDTH, -15])
    rotate([0, 0, 0])
    cube ([CHANNEL_HEIGHT,CHANNEL_WIDTH/2,PIPE_LENGTH-20]);

    translate ([-(CHANNEL_HEIGHT/2), CHANNEL_WIDTH/2, -15])
    rotate([0, 0, 0])
    cube ([CHANNEL_HEIGHT,CHANNEL_WIDTH/2,PIPE_LENGTH-20]);

// Flow plates

    translate ([-(CHANNEL_HEIGHT/2)-1, -CHANNEL_WIDTH/2, -25])
    rotate([0, 0, 0])
    cube ([1,CHANNEL_WIDTH,20]);

    translate ([-(CHANNEL_HEIGHT/2)-1, -CHANNEL_WIDTH/2, 12])
    rotate([0, 0, 0])
    cube ([1,CHANNEL_WIDTH,20]);

    translate ([CHANNEL_HEIGHT/2), -CHANNEL_WIDTH/2, PIPE_LENGTH-45])
    rotate([0, 0, 0])
    cube ([1,CHANNEL_WIDTH,20]);

    translate ([CHANNEL_HEIGHT/2), -CHANNEL_WIDTH/2, PIPE_LENGTH-85])
    rotate([0, 0, 0])
    cube ([1,CHANNEL_WIDTH,20]);

}

}

```

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