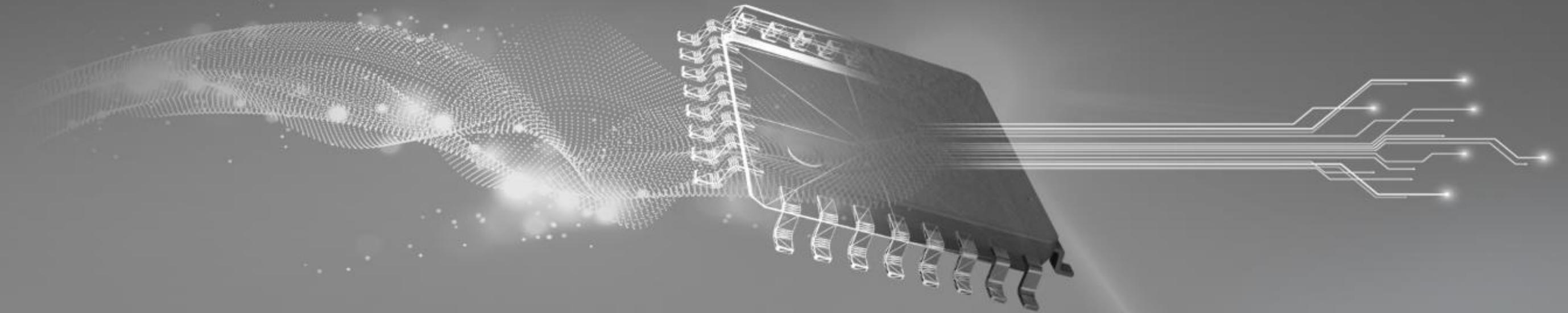


TI TECH DAYS



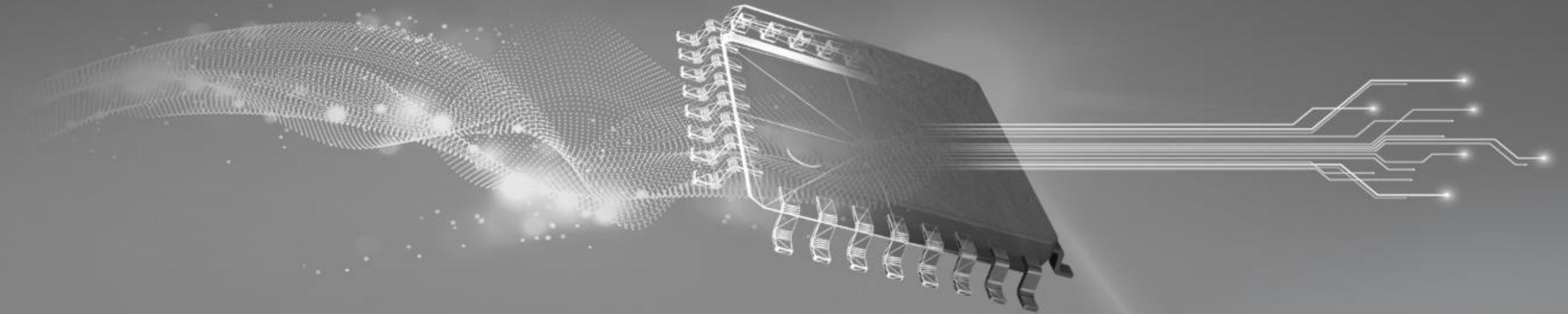
Designing in emerging applications: Ultrasonic sensing and capacitive touch

Presenters:

Leo Estevez – MSP430 Applications

Dennis Lehman – MSP430 Applications

TI TECH DAYS



Ultrasonic Liquid Level Sensing

Presenter: Leo Estevez – MSP430 Applications

Agenda

TI's Solution

Test fixtures

Transducers

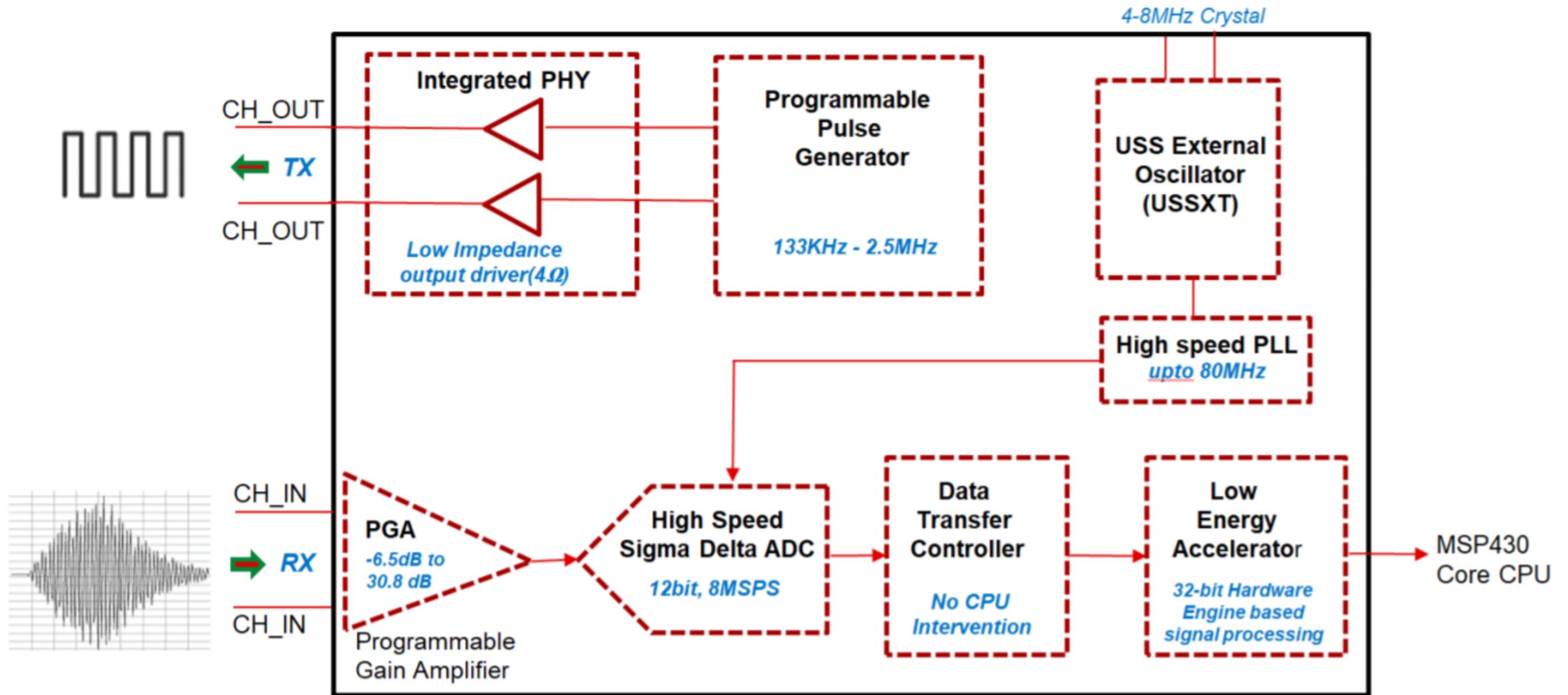
Adverse operating conditions

Additional applications and demo

Technology/Cost comparisons

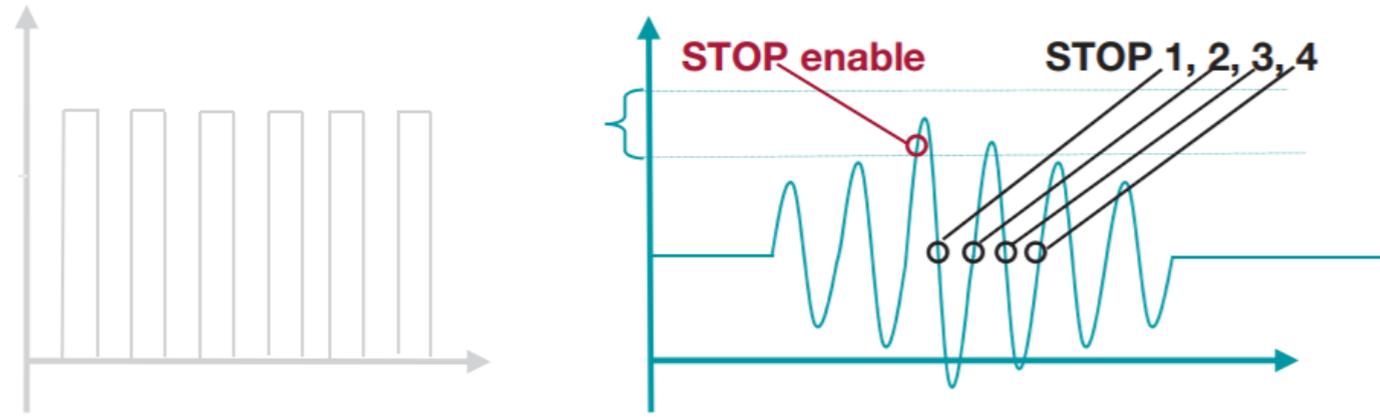
- In liquid sensors are prone to corrosion/mechanical failure and can't work with arbitrary containers. (drink dispensers, coffee machines, etc.)
- The additional cost of a transducer can be 50 cents(in high volumes).
 - The transducer can often be fit directly into the chassis of the tank or machine and doesn't require modification to the container itself.
- Ultrasonic level sensing enables resolutions(**~20 microns**) which could enable feedback for flow control while dispensing fluid from a container(or to a container).
- Average current consumption is **<20uA** per measurement per second.

TI's ultrasonic sensing solution (MSP43FR604x)



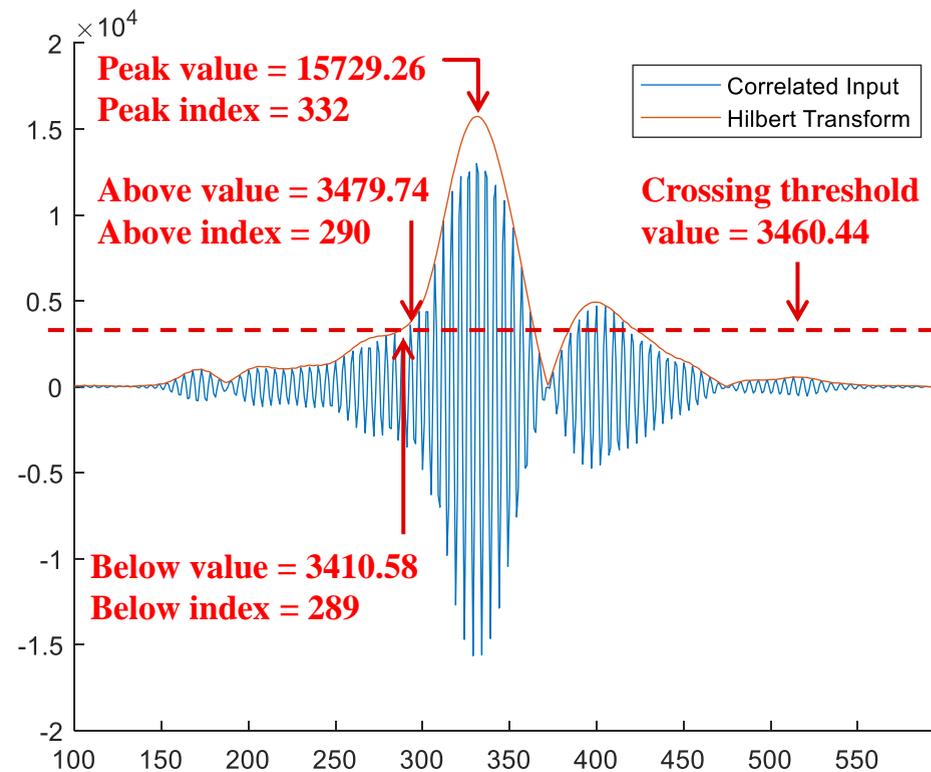
ADC based correlation vs. TDC zero crossing

TDC
Zero-Crossing
(Amplitude
Dependent)



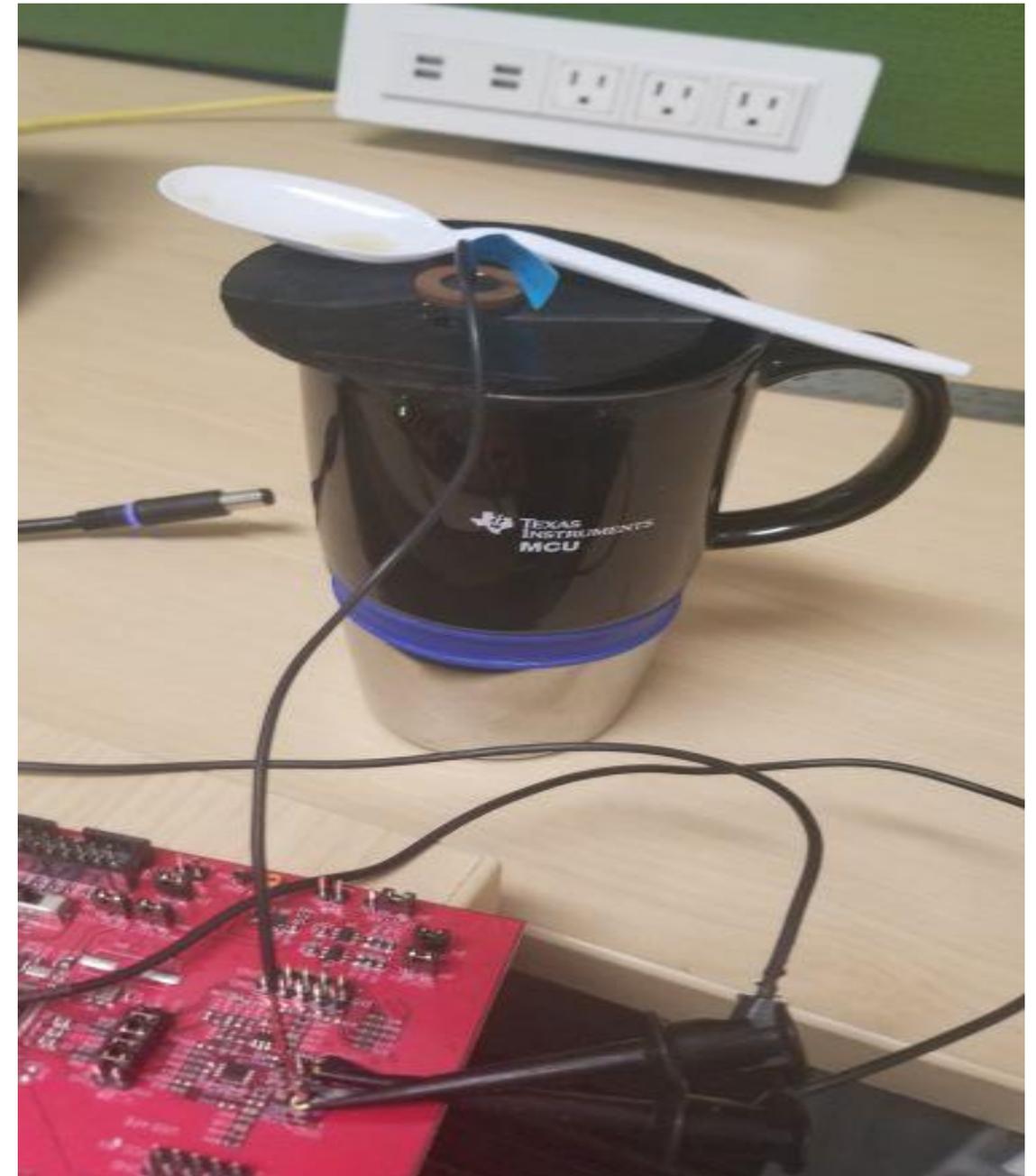
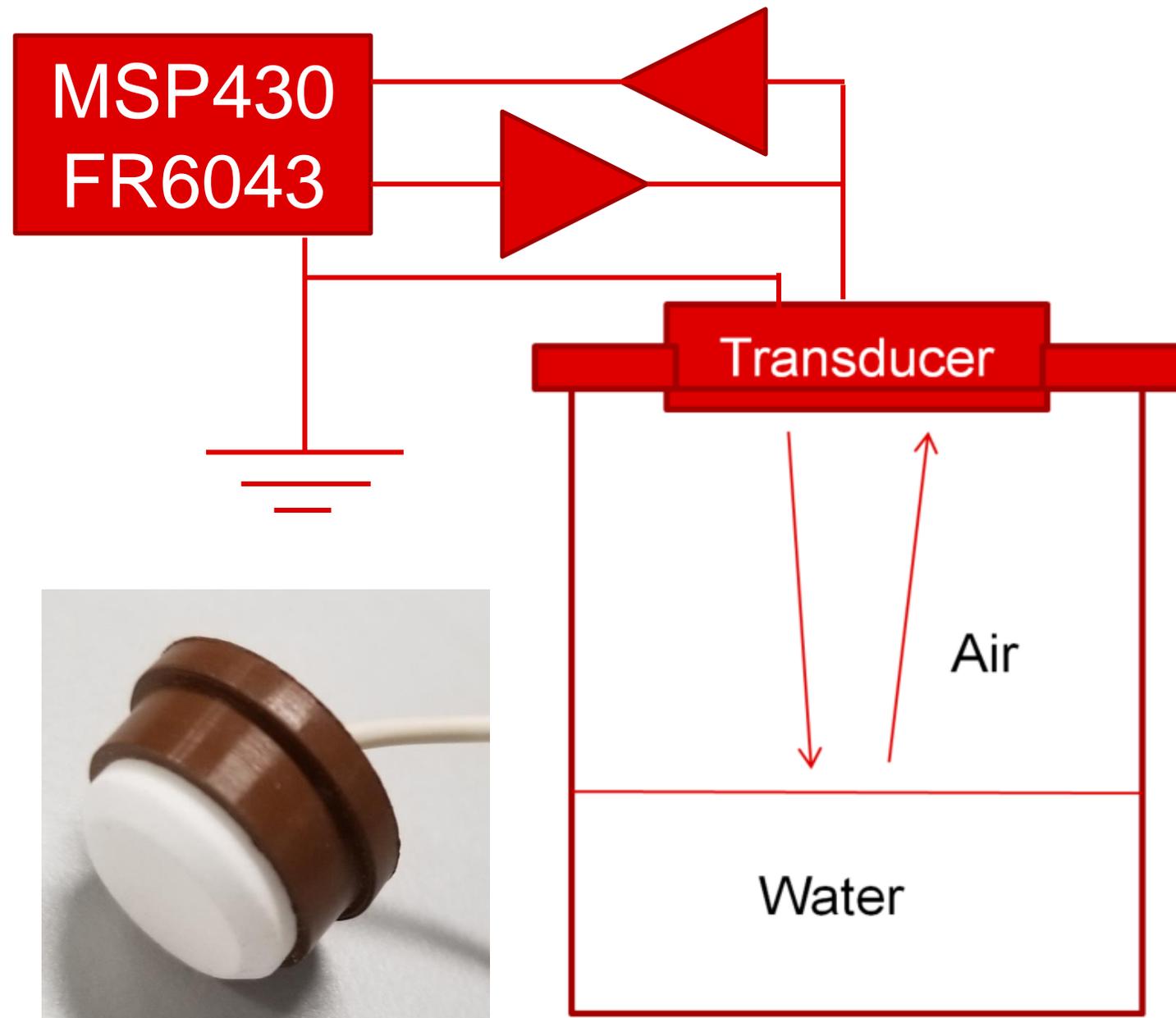
1. Stop timer when threshold exceeded.
2. Find subsequent zero crossings.

ADC Based
Correlation
(Amplitude
Independent)



1. Perform full correlation of input with binary transmit pattern
2. Compute Hilbert transform
3. Find envelope peak value and index
4. Calculate threshold using the peak value
5. Interpolate to find threshold crossing.

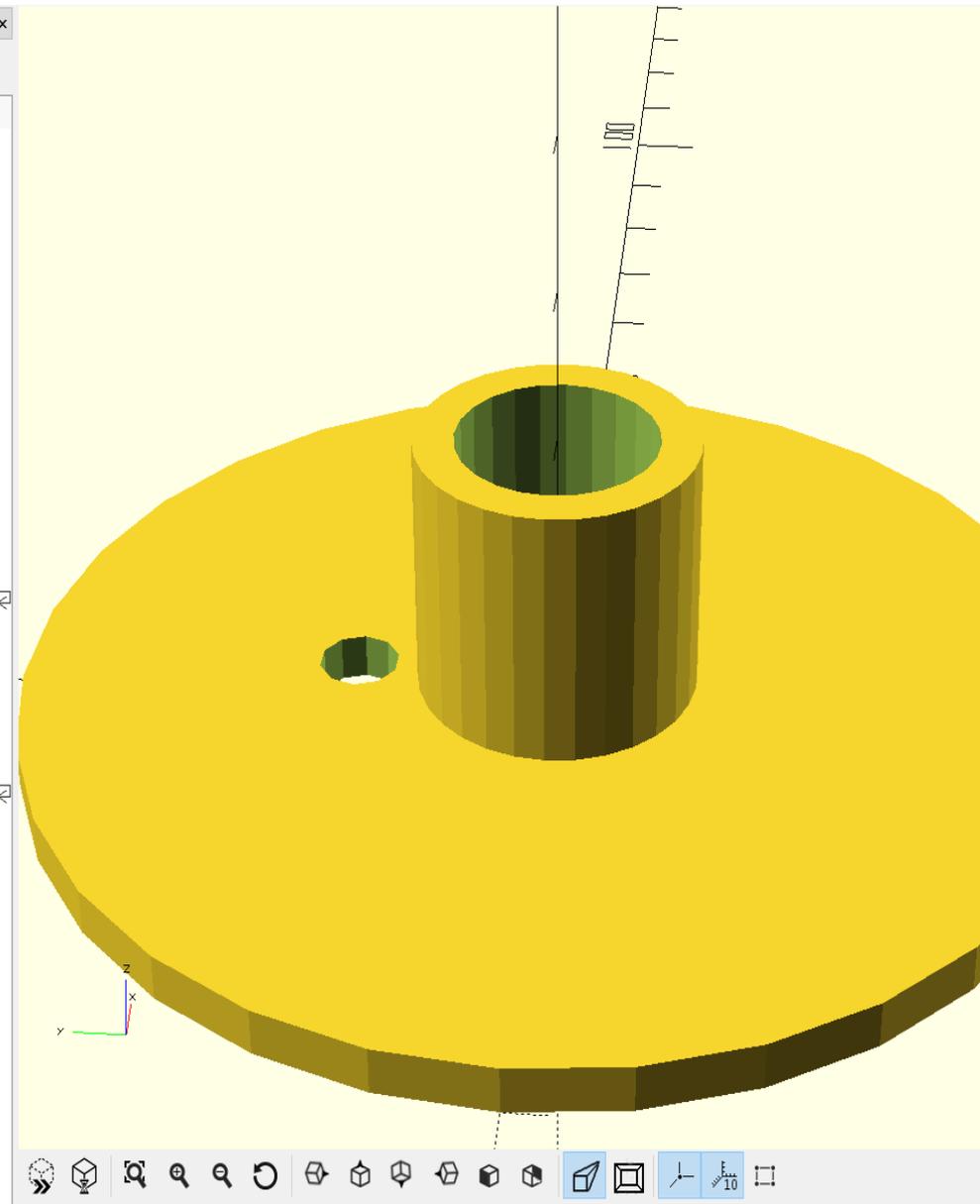
Ultrasonic configuration



<http://www.ti.com/lit/an/slaa951a/slaa951a.pdf>

OpenSCAD test fixtures

```
File Edit Design View Help
ditor
1 TRANSDUCER_RADIUS=7.5;
2 HOLE_RADIUS=3;
3 LID_RADIUS=40;
4 LID_LENGTH=3;
5 CYLINDER_LENGTH=20;
6
7
8 difference(){
9   union(){
10    translate ([0, 0, 0])
11    rotate([0, 0, 0])
12    cylinder (h = LID_LENGTH, r = LID_RADIUS);
13
14    translate ([0, 0, 0])
15    rotate([0, 0, 0])
16    cylinder (h = CYLINDER_LENGTH, r =
TRANSDUCER_RADIUS+3);
17  }
18  union(){
19    translate ([0, 0, 0])
20    rotate([0, 0, 0])
21    cylinder (h = CYLINDER_LENGTH, r =
TRANSDUCER_RADIUS);
22
23    translate ([0, 15, 0])
24    rotate([0, 0, 0])
25    cylinder (h = LID_LENGTH, r = HOLE_RADIUS);
26  }
27 }
28
29
```



200kHz

175kHz

500kHz

<http://www.openscad.org/>

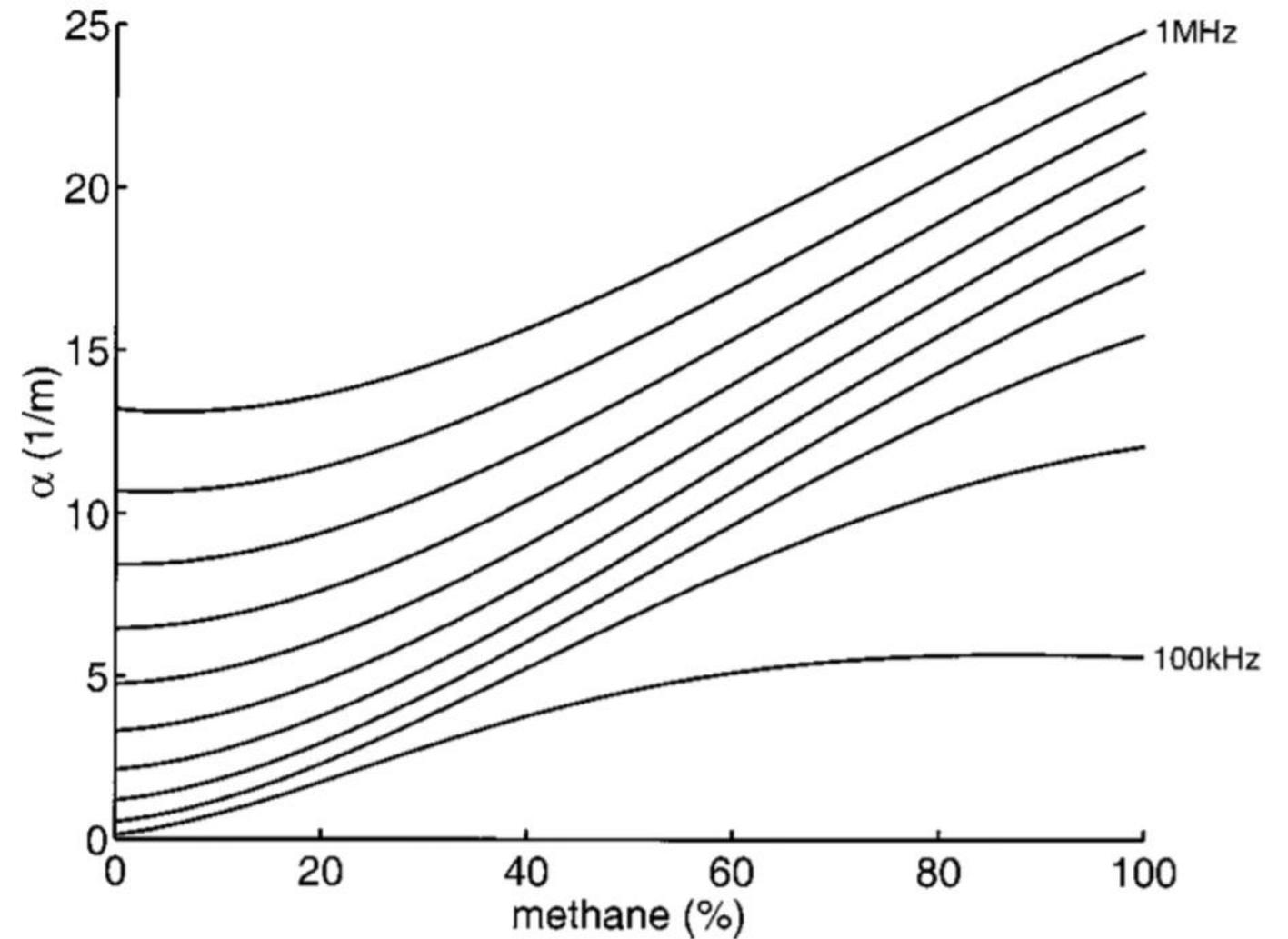
Tradeoffs in transducers

Frequency	3.3V Excitation Range	8 Pulse Standard Deviation	Minimum Distance
175kHz	> 100 cm	100-500 ns	3.5 cm
200kHz	20 cm	50-400 ns	1.5 cm
500kHz	15 cm	10-300 ns	1 cm

The standard deviation in measurements increases with distance.

Increasing excitation voltage and/or a collimating waveguide can extend range.

The attenuation of the ultrasonic wave increases with frequency and can vary based on the gas mixture.



500kHz @12cm

Parameters Advanced Parameters Calibration

Software Parameters

Transmit frequency (kHz) F1 490 F2 540 F1 to F2 Sweep

Gap between pulse start and ADC capture (µs) 550

Number of Pulses 8

UPS and DNS Gap (µs) 8,000

UPS0 to UPS1 Gap (ms) 150

GUI Based Gain Control 21.5 db

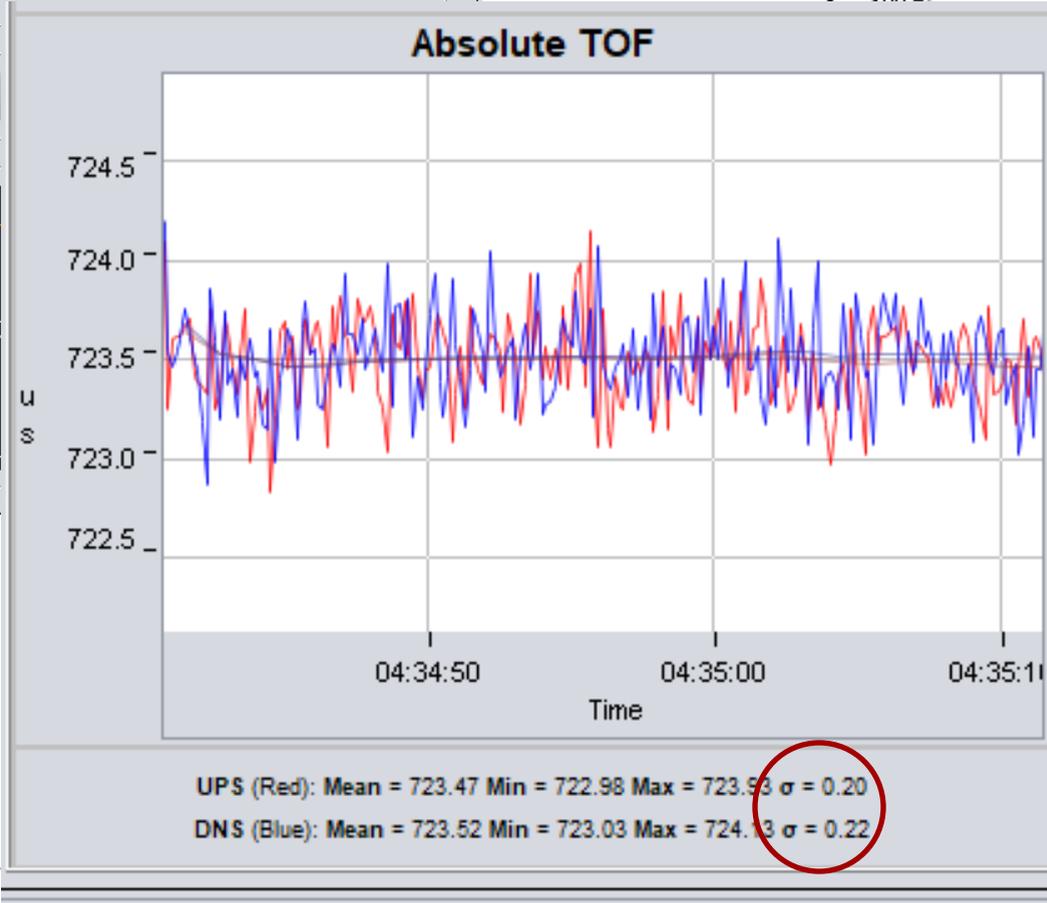
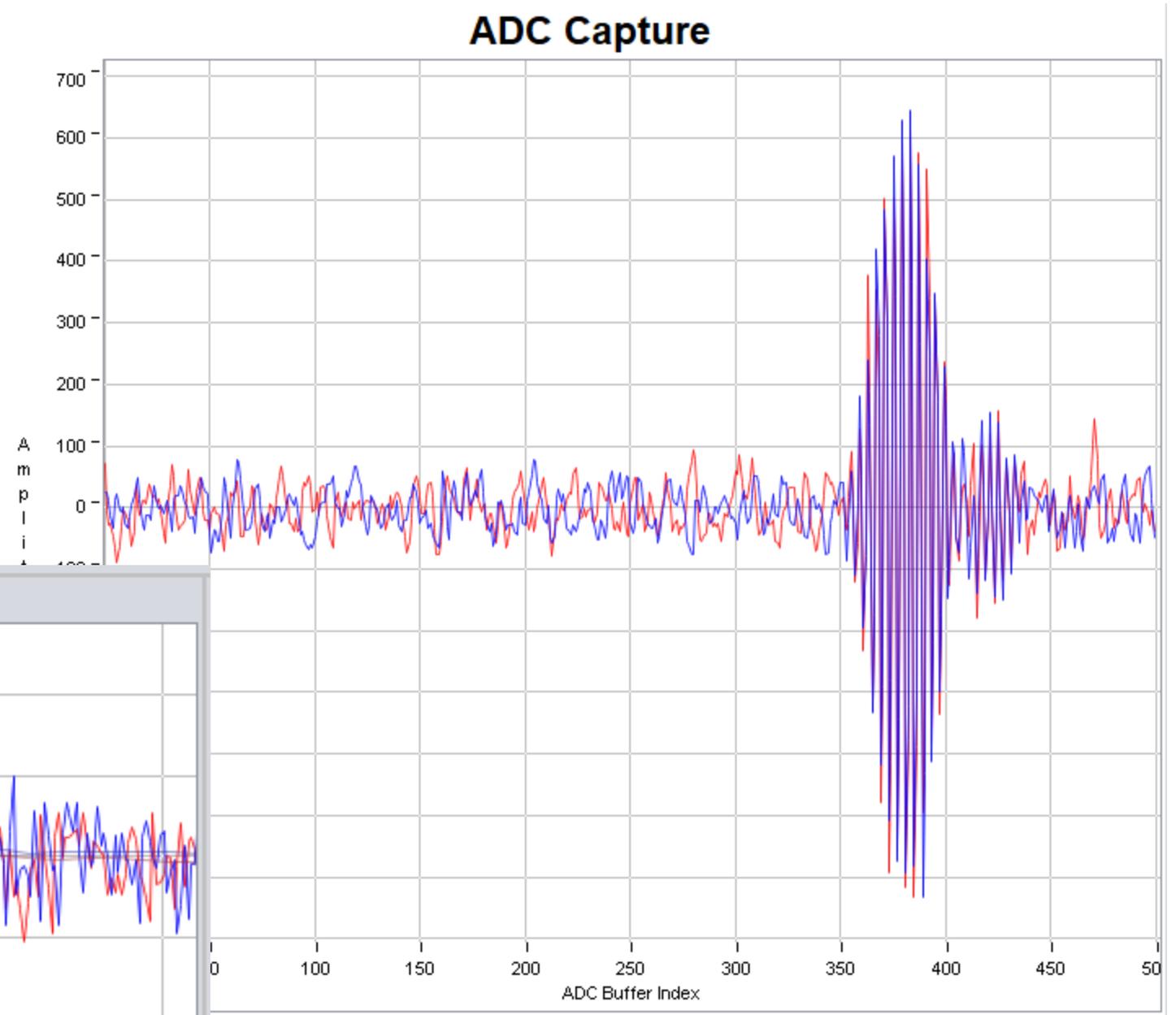
Meter Constant 61.00

Options

Timing Diagram

Channel 0: 8 Excitation Pulses, 150 UPS0 to UPS1 Gap (ms)

Channel 1: 8000 UPS and DNS Gap (µs)



$$0.2\mu\text{s} * 343\text{m/s} = 68.6\mu\text{m}$$

(34.3µm one way)

200kHz @10cm

Parameters | Advanced Parameters | Calibration

Software Parameters

Transmit frequency (kHz) F1: 170 F2: 220 F1 to F2 Sweep

Gap between pulse start and ADC capture (μ s): 500

Number of Pulses: 8

UPS and DNS Gap (μ s): 8,000

UPS0 to UPS1 Gap (ms): 150

GUI Based Gain Control: 18.8 db

Meter Constant: 61.00 μ h G/m

Options

Request Update Save Configuration Load Configuration Reset Va

Timing Diagram

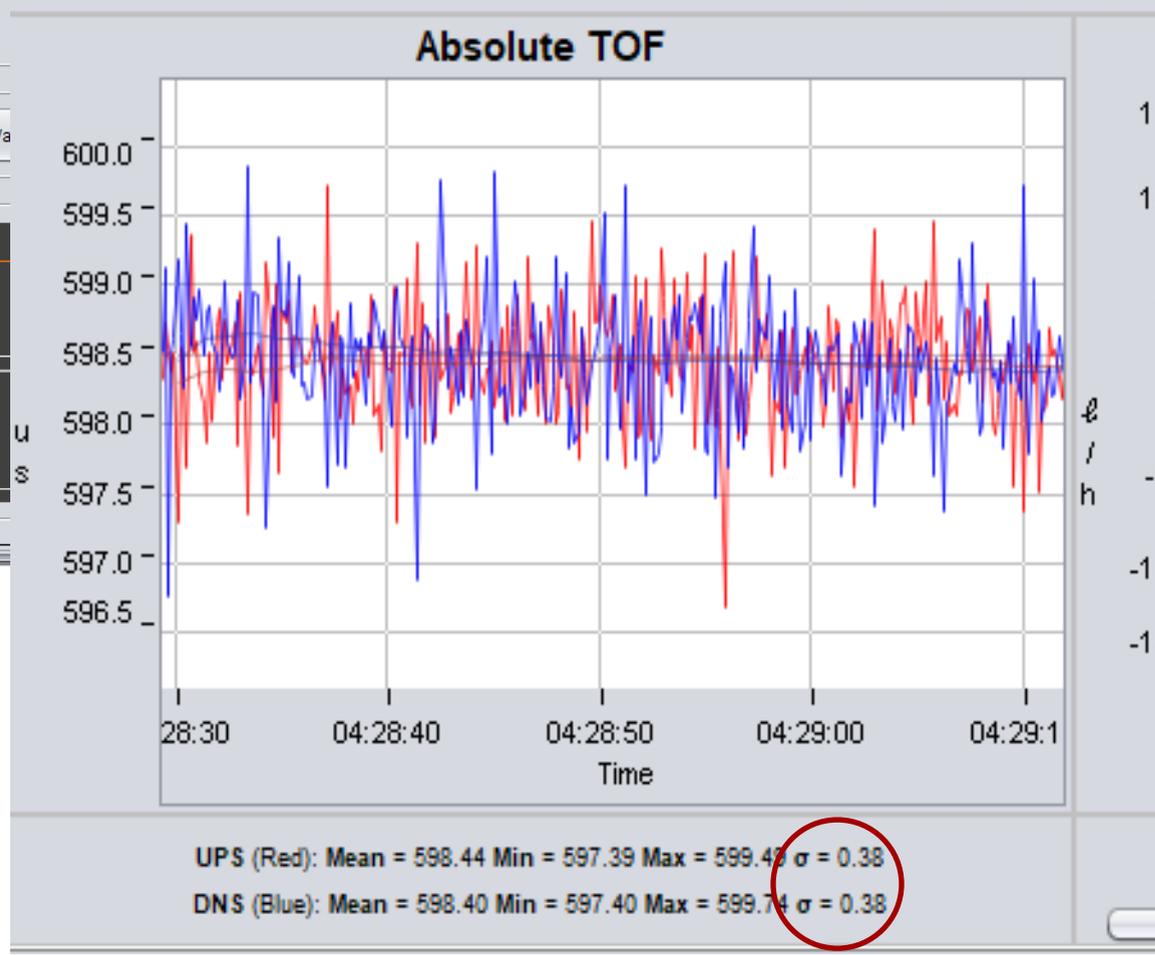
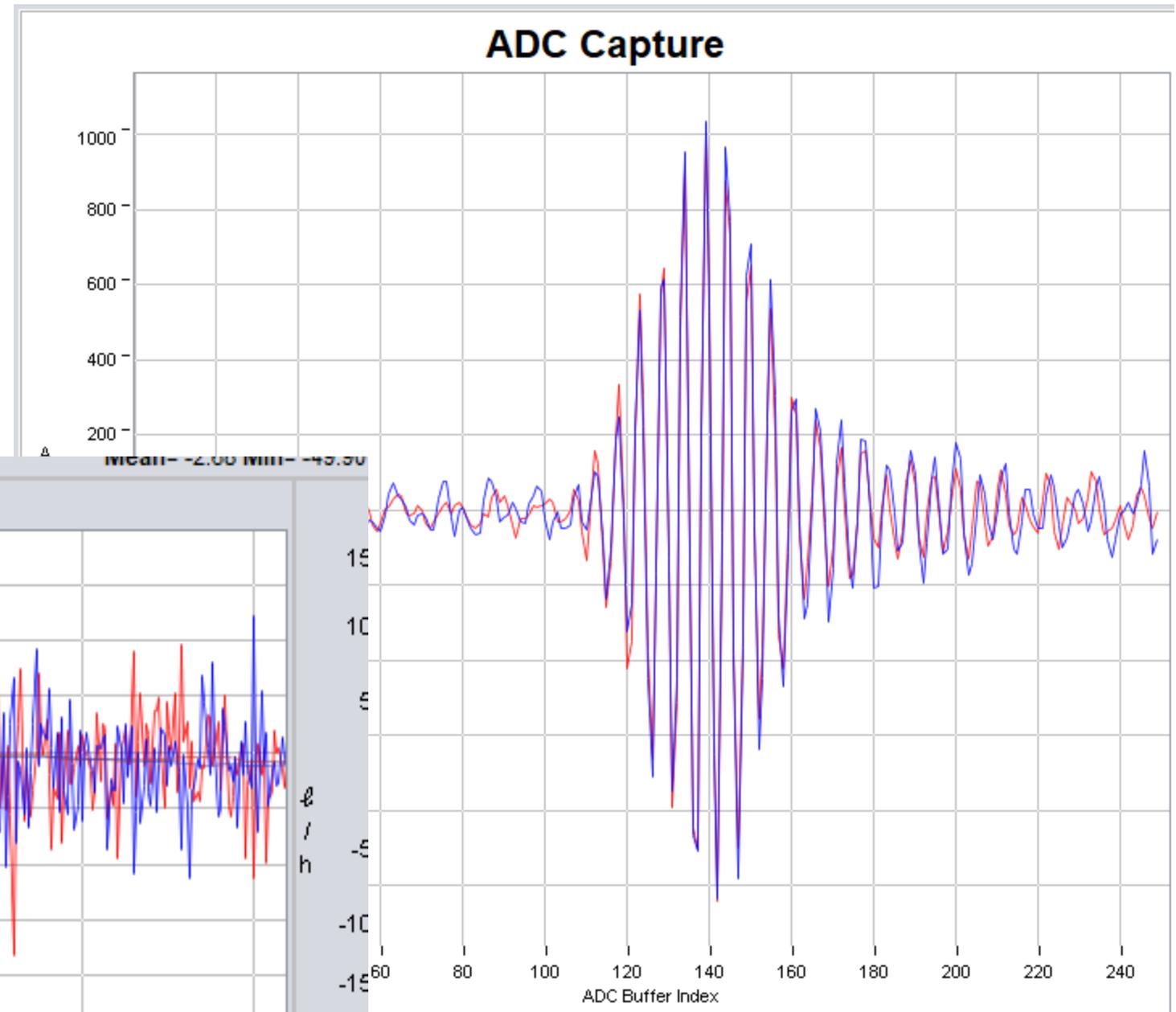
8 Excitation Pulses

150 UPS0 to UPS1 Gap (ms)

8000 UPS and DNS Gap (μ s)

Channel 0

Channel 1



$0.4\mu\text{s} * 343\text{m/s} = 137.2\mu\text{m}$
(68.6 μm one way)

175kHz @10cm

Parameters Advanced Parameters Calibration

Software Parameters

Transmit frequency (kHz) F1: 170 F2: 180 F1 to F2 Sweep

Gap between pulse start and ADC capture (μ s) 500

Number of Pulses 8

UPS and DNS Gap (μ s) 8,000

UPS0 to UPS1 Gap (ms) 150

GUI Based Gain Control 4.4 db

Meter Constant 61.00 ℓ/h G/m

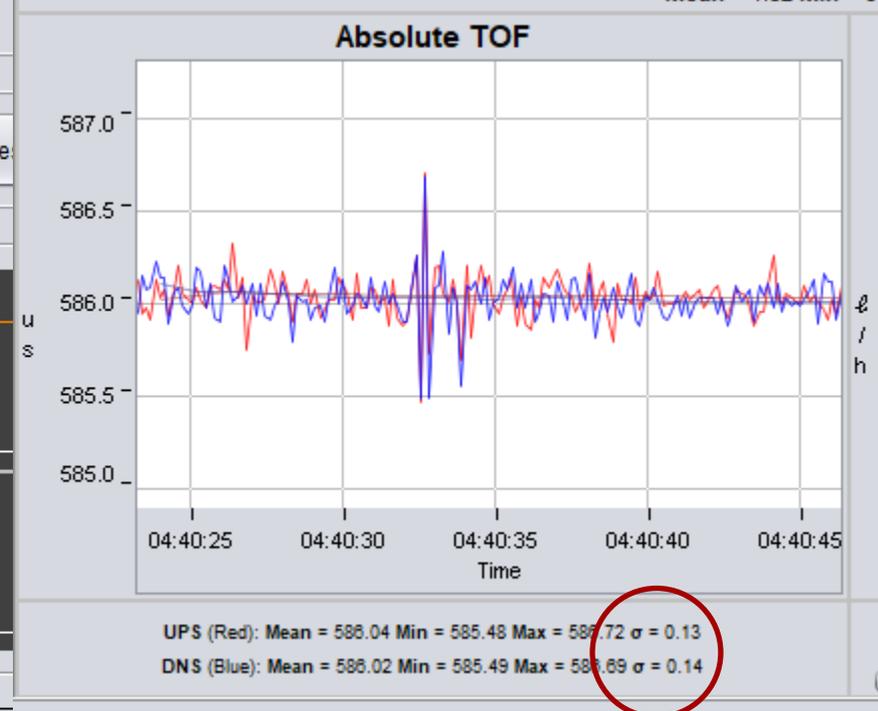
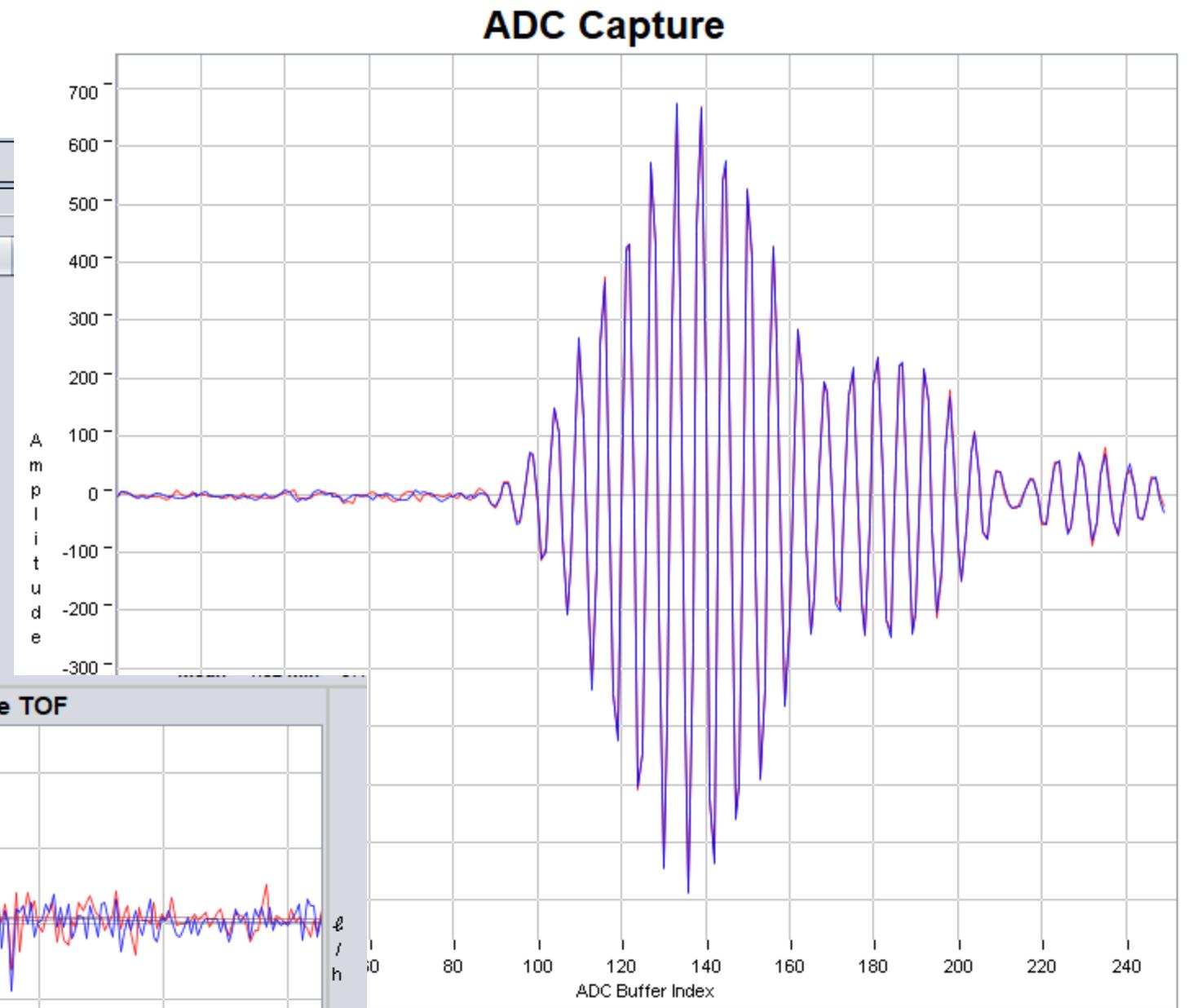
Options

Request Update Save Configuration Load Configuration Re...

Timing Diagram

Channel 0: 8 Excitation Pulses, 150 UPS0 to UPS1 Gap (ms)

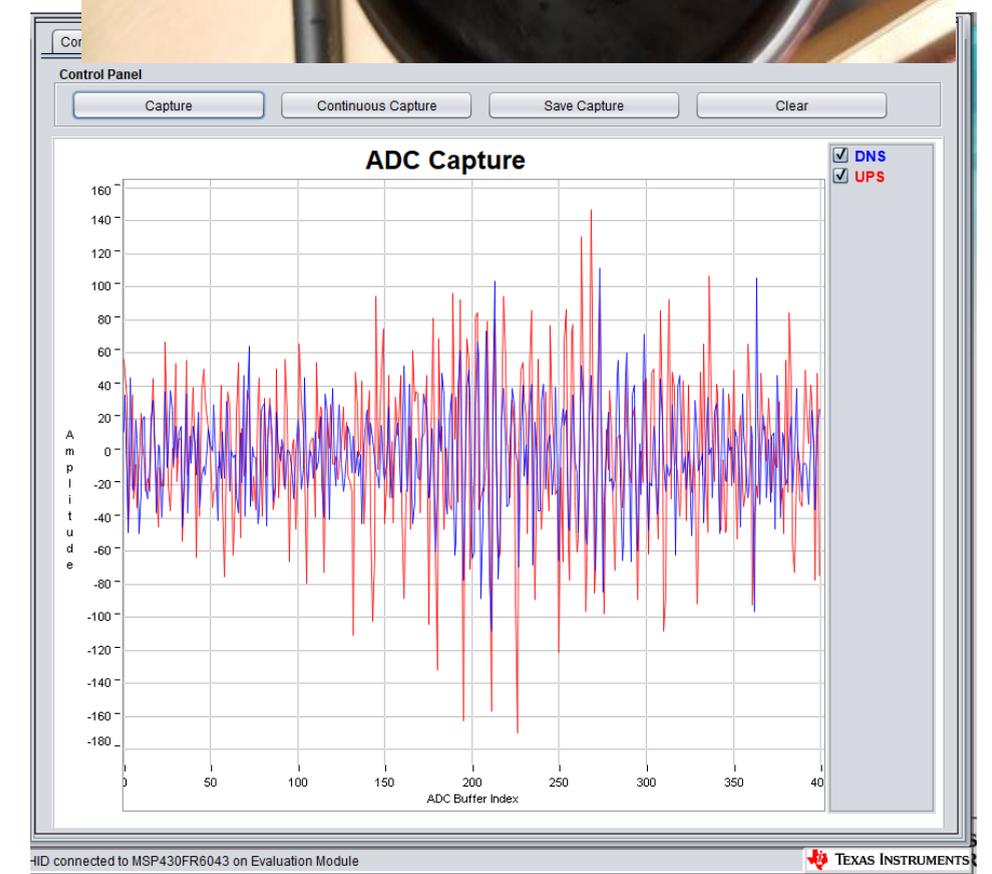
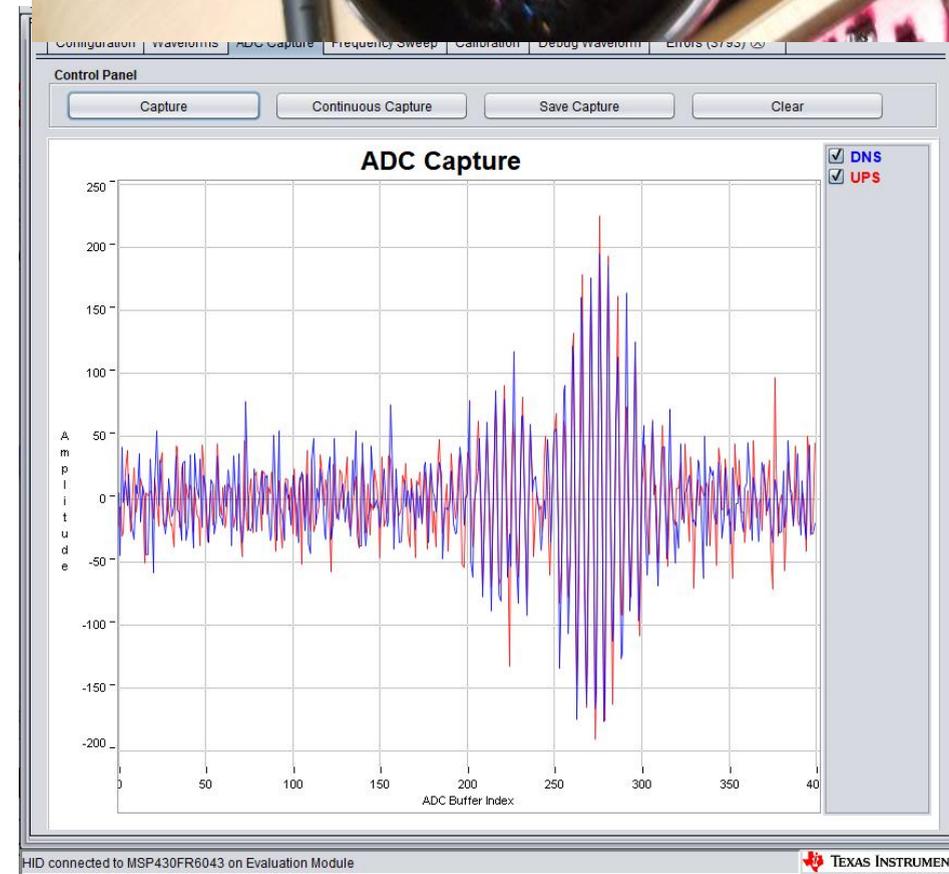
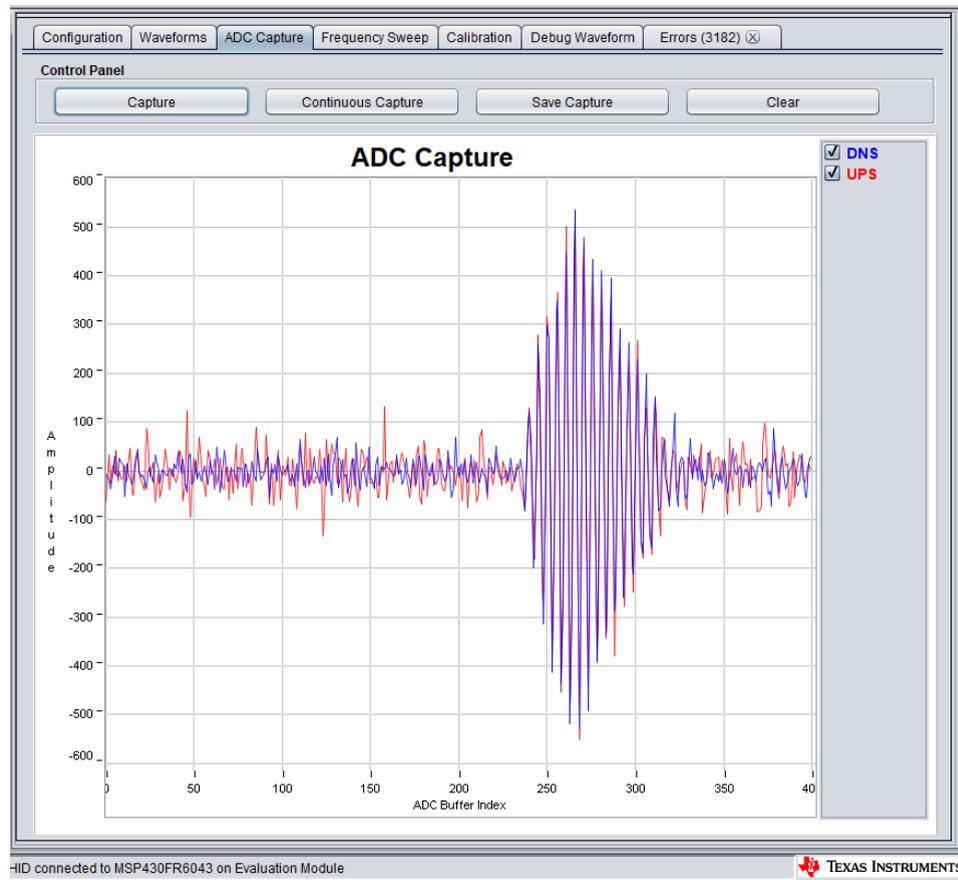
Channel 1: 8000 UPS and DNS Gap (μ s)



$$0.13\mu\text{s} * 343\text{m/s} = 44.6\ \mu\text{m}$$

(22.3 μm one way)

200kHz foam experiments

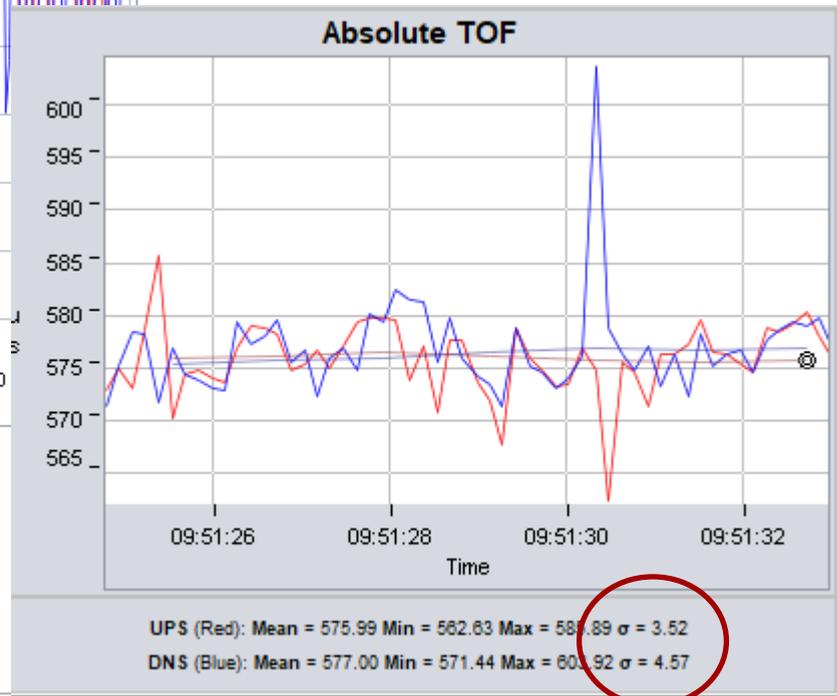
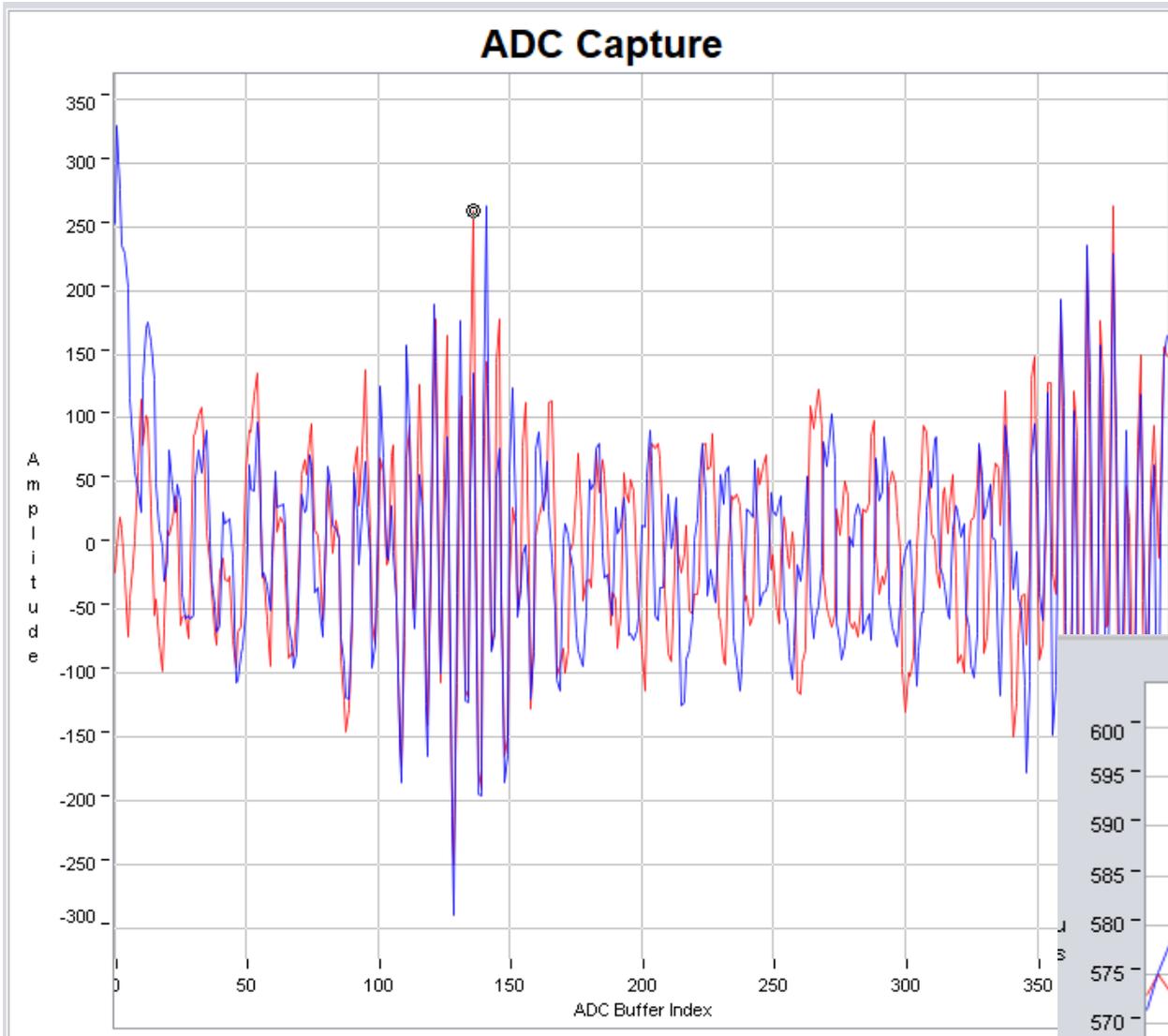


No Foam

Some Foam

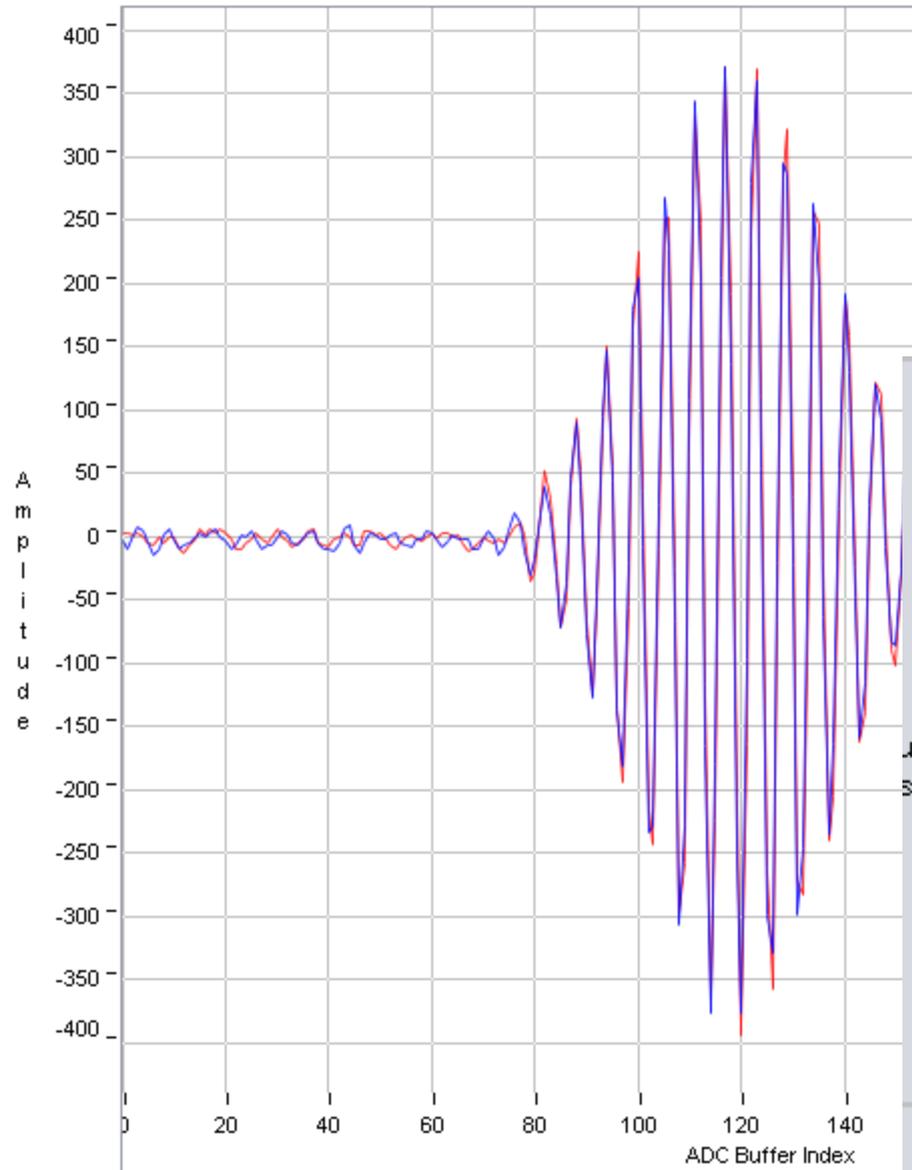
More Foam

200kHz condensation effects

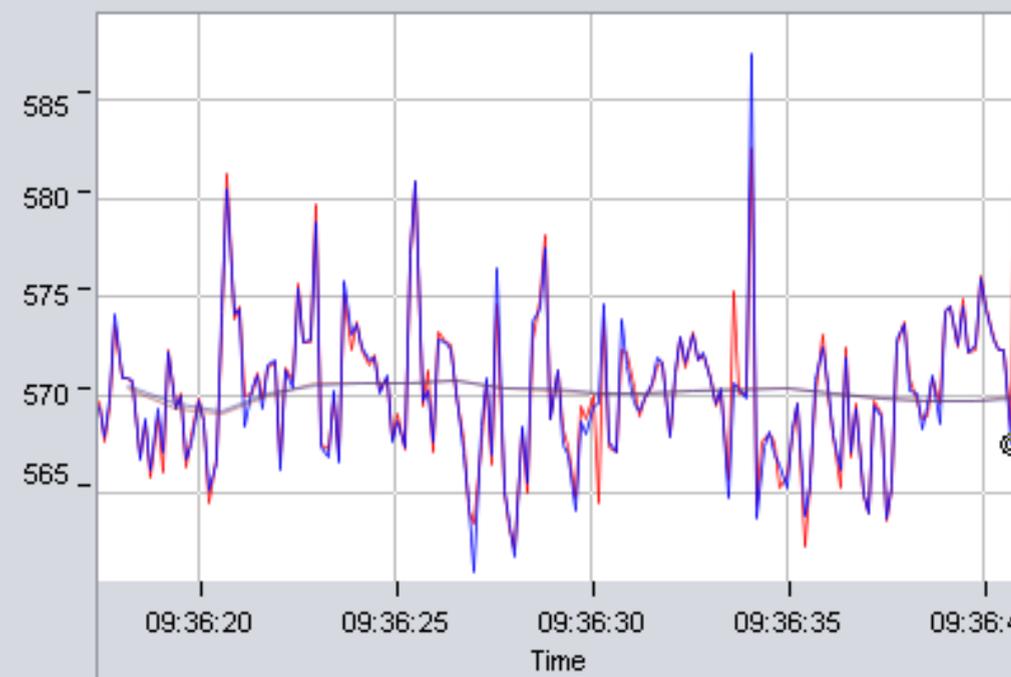


175kHz condensation effects

ADC Capture



Absolute TOF

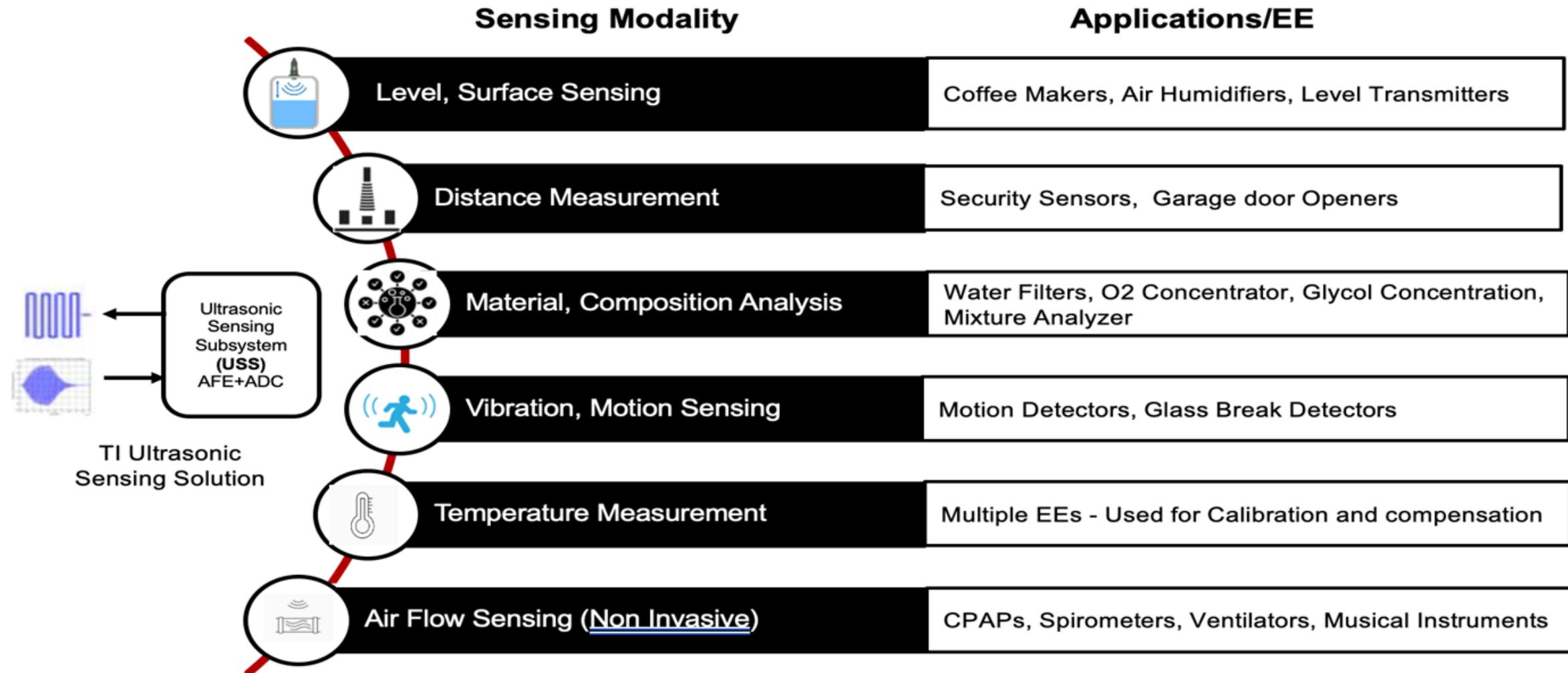


UPS (Red): Mean = 570.07 Min = 562.27 Max = 588.80 $\sigma = 4.06$
DNS (Blue): Mean = 569.92 Min = 561.07 Max = 587.56 $\sigma = 3.80$



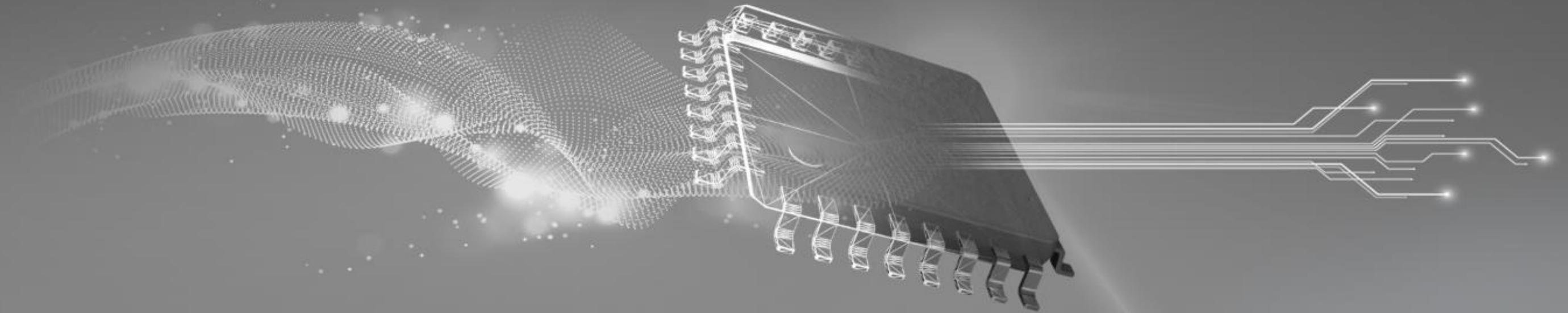
$4\mu\text{s} * 343\text{m/s} = 1.37\text{mm}$
(0.68 mm one way)

Additional applications/demo



www.ti.com/tool/evm430-fr6043
(Technical Documents)

TI TECH DAYS



Automated tools make capacitive sensor design quick and easy

Presenter: Dennis Lehman – MSP430 Applications

Agenda

CapTivate™ Technology

Automating Sensor Designs

CapTivate Design Center

OpenSCAD Demo

MSP430™ **capacitive touch sensing** microcontrollers

CapTIvate™ MCUs: Easiest to use capacitive touch solutions

MSP430™ capacitive touch sensing MCUs feature CapTIvate™ technology offering the lowest power capacitive touch solutions. With support from 1 to 64 buttons, sliders, wheels and proximity with reliable performance in wet, dirty and greasy conditions as well as through metal, glass, plastic and other overlays, we have a capacitive touch solution for your MCU-based design.

Agenda

CapTivate™ Technology

Automating Sensor Designs

CapTivate Design Center

OpenSCAD Demo

CapTivate Technology Guide highlights

- <https://ti.com/captivatetechguide>
 - MSP430 CapTivate MCU selection
 - CapTivate Technology
 - Sensor design guidelines
 - CapTivate Design Center GUI
 - Development Tools
 - Getting Started Workshop
 - Video
 - [Tune capacitive sensors in 5mins or less](#)

The image displays two screenshots related to the CapTivate technology. The top screenshot shows the 'CapTivate™ Technology Guide' website interface, featuring the Texas Instruments logo, a search bar, and a navigation menu with categories like 'Getting Started with CapTivate', 'Design Guide', 'Best Practices', and 'Buttons'. The bottom screenshot shows the 'CapTivate Design Center GUI' software interface, which includes a menu bar (File, Edit, Options, Communications, Help), a toolbar with various sensor icons, and a main workspace containing an 'MSP430' microcontroller component and a 'buttons' component with four sensor elements labeled RX00, RX01, RX02, and RX03.

CapTivate tools



EVALUATION BOARD

CAPTIVATE-FR2633 – Capacitive touch MSP430FR2633 MCU board



DEVELOPMENT KIT

CAPTIVATE-PHONE – Capacitive touch mutual capacitance sensor demonstration board with haptic feedback



EVALUATION BOARD

CAPTIVATE-BSWP – Capacitive touch self capacitance button, slider, wheel, and proximity sensor demonstration board



HARDWARE PROGRAMMING TOOL

CAPTIVATE-PGMR – MSP430 CapTivate™ MCU programmer



EVALUATION BOARD

CAPT-FR2633-BNDL – CAPTIVATE-FR2633 + CAPTIVATE-BSWP + CAPTIVATE-PHONE + CAPTIVATE-PGMR bundle

Agenda

CapTivate™ Technology

Automating Sensor Designs

CapTivate Design Center

OpenSCAD Demo

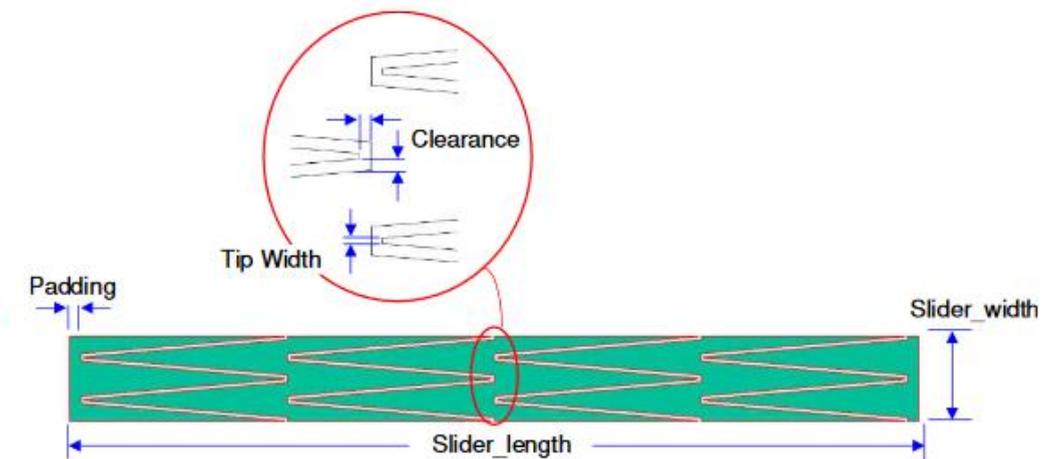
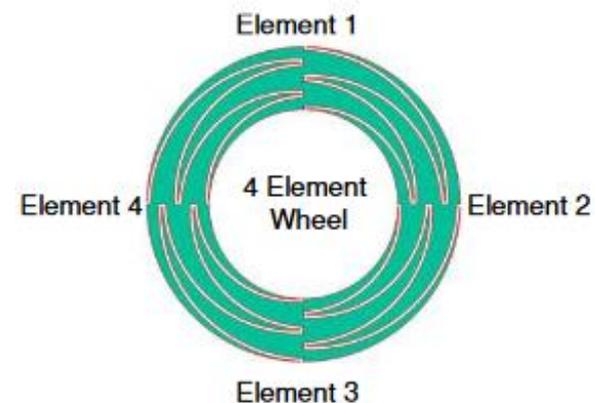
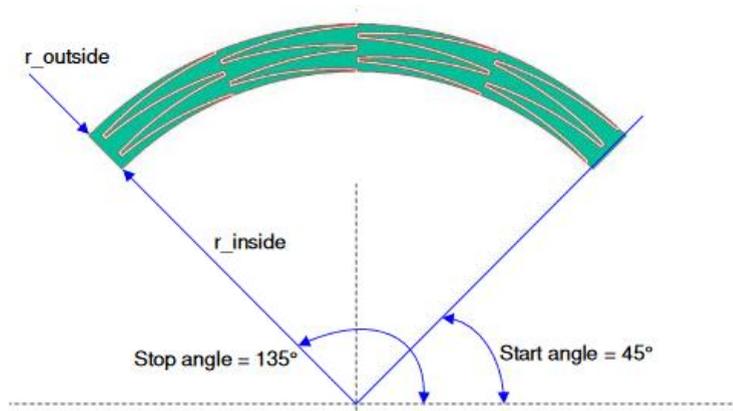
Automating PCB sensor design

- CapTIvate Tech Guide – Design Guide Chapter
- SLAA891- OpenSCAD auto-generates electrode patterns in seconds
- Scripts for sliders, curved sliders, wheels and touchpads provided by TI



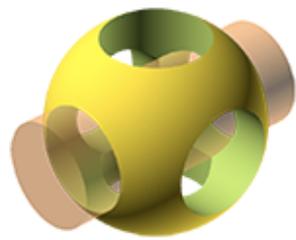
Application Report
SLAA891B–April 2019–Revised February 2020

Automating Capacitive Touch Sensor PCB Design Using OpenSCAD Scripts



Automating PCB sensor design

- OpenSCAD
 - <https://www.openscad.org>
- Open Source (free)
- 2D/3D CAD
- Programming script controls sensor design



OpenSCAD

The Programmers Solid 3D CAD Modeller

```
49 // MSP430 Applications
50 // version 1.0
51 // Aug 22, 2020
52
53 // ===== CONSTANTS =====
54 // DON'T CHANGE THESE
55 $fn = 400; // Defines number of fragments
56 $circle = 0; // Defines for shapes
57 $rectangle = 1;
58 $custom = 2;
59 $none = 3; // No shape shows entire diamond matrix (development
// purposes)
60 $x_max = 20; // Maximum number or supported columns + 1
61 $y_max = 20; // Maximum number of supported rows + 1
62
63 //===== USER INPUTS =====
64 // #1 - SPECIFY IF ROUND OR SQUARE OR CUSTOM
65 shape = $custom;
66
67 // #2 - SPECIFY THE NUMBER OF RX AND TX
68 rows = 7;
69 columns = 6;
70
71 // #3 - SPECIFY THE WIDTH AND HEIGHT OF THE TOUCHPAD IN UNITS
72 // IF CIRCLE, WIDTH AND HEIGHT SHOULD BE SET EQUAL
73 // IF CUSTOM, REFER TO DXF OUTPUT
74 touchpad_width = 50;
75 touchpad_height = 60;
76
77 // #4 - SPECIFY THE EDGE TO EDGE SPACING BETWEEN DIAMONDS
78 diamond_spacing = .4;
79
80 // #5 - SPECIFY DXF FILE TO IMPORT
81 dxf = "50x60mm_ellipse.dxf"; // example file (20mm x 14mm ellipse)
82
83 // #6 - (OPTIONAL FOR CUSTOM) SPECIFY OBJECT ROTATION (DEGREES)
84 sensor_rotation = 0;
85
86 // #7 - (OPTIONAL FOR CUSTOM) CORRECT XY DXF OFFSET OR SCALE SIZE
87 dxf_offset_x = -0.5;
88 dxf_offset_y = 0;
89 dxf_scale_x = 1.0;
90 dxf_scale_y = 1.0;
91
```

The screenshot shows the OpenSCAD editor interface. The left pane displays a script for generating a diamond-shaped sensor array. The right pane shows a 3D preview of the resulting circular sensor array, which is a grid of green diamonds with red outlines, arranged in a circular pattern. The console at the bottom right shows the output of the design compilation, including the CSG tree generation and various parameters like shape, diamond_x, diamond_y, tip-tip spacing, pitch_x, pitch_y, sensor_rotation, dxf x translation, dxf y translation, and estimated min finger size.

Automating PCB sensor design

- Scripts can be customized by user
- Requires only a few parameters to define a sensor design

```
53 // USER DEFINED INPUTS:
54 //=====
55 // STEP #1
56 // USER DEFINED NUMBER OF ELEMENTS IN THE SLIDER (MIN IS 3, TYPICAL IS 4)
57 total_elements = 4;
58
59 // STEP #2
60 // USER DEFINED NUMBER OF FINGERS (TINES) (TYPICAL = 5)
61 tines = 5;
62
63 // STEP #3
64 // USER DEFINED LENGTH (mm IN THIS EXAMPLE)
65 slider_length = 150;
66
67 // STEP #4
68 // USER DEFINED WIDTH (mm IN THIS EXAMPLE)
69 slider_width = 15;
70
71 // STEP #5
72 // USER DEFINED LEFT AND RIGHT END PADDING SIZE (mm IN THIS EXAMPLE)
73 //(mm IN THIS EXAMPLE)
74 padding = 2;
75
76 // STEP #6
77 // USER DEFINED CLEARANCES AND TIP WIDTH (mm IN THIS EXAMPLE)
78 //(mm IN THIS EXAMPLE)
79 clearance = 0.5;
80 tip_width = 0.25;
81
```

OpenSCAD design process

- Live Demo at end of presentation

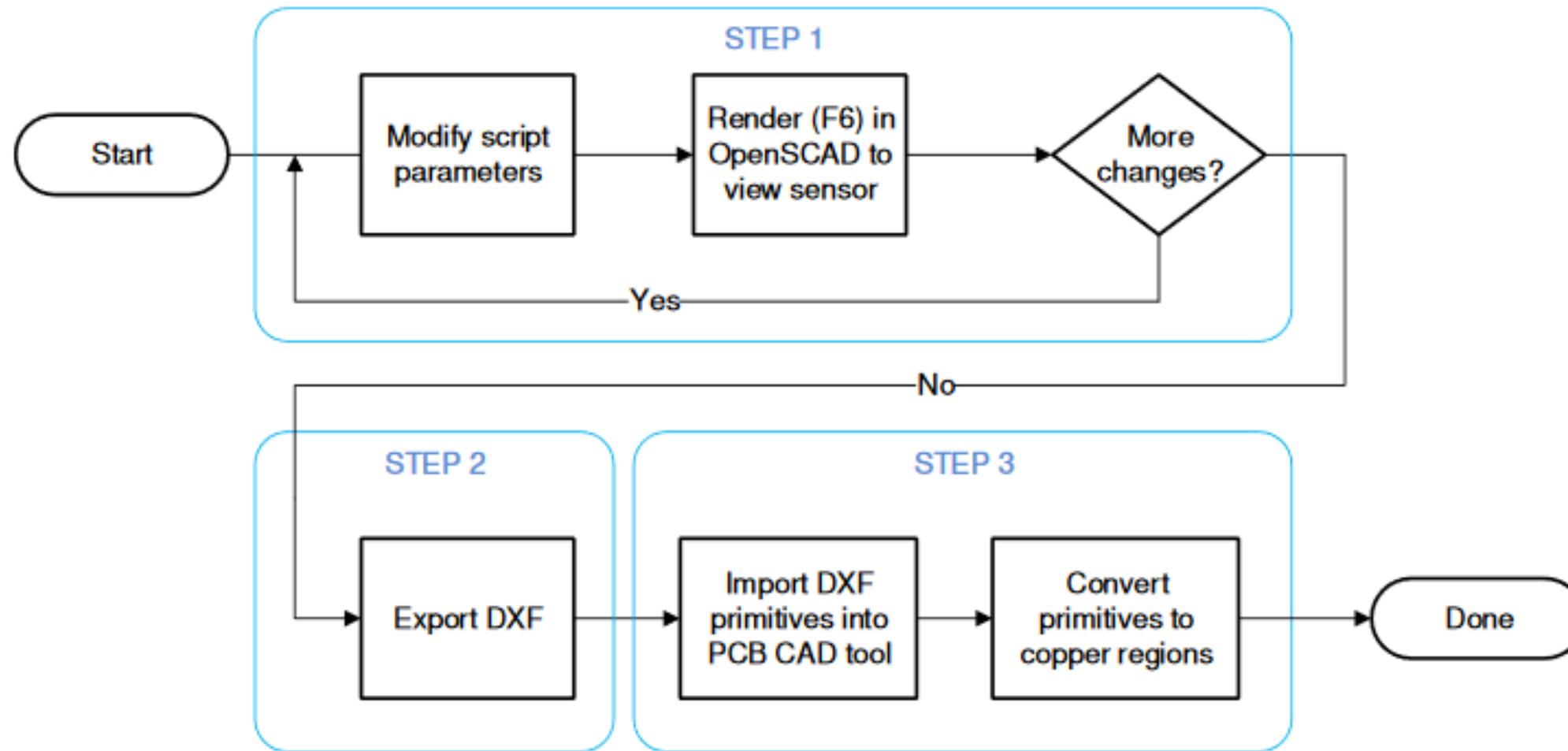


Figure 1. Workflow

Agenda

CapTivate™ Technology

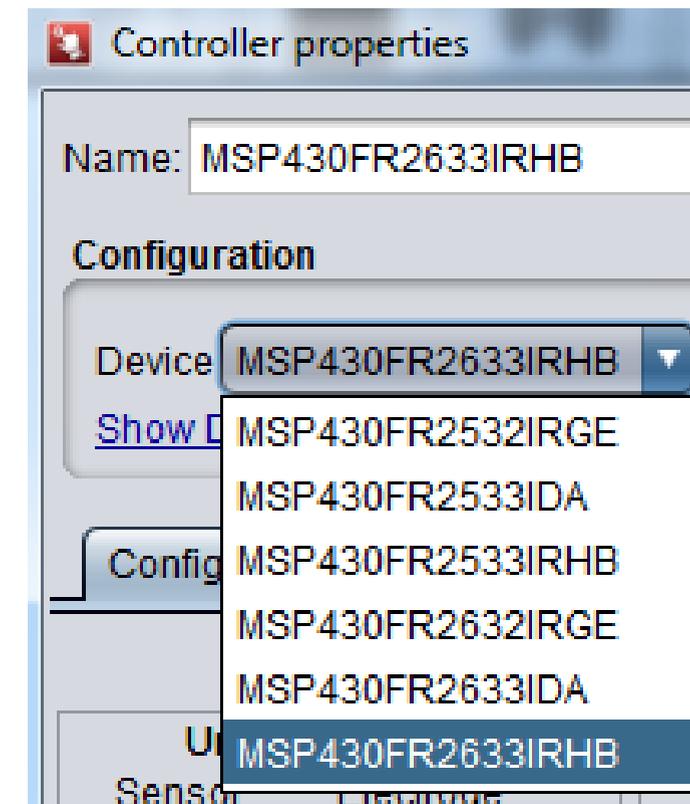
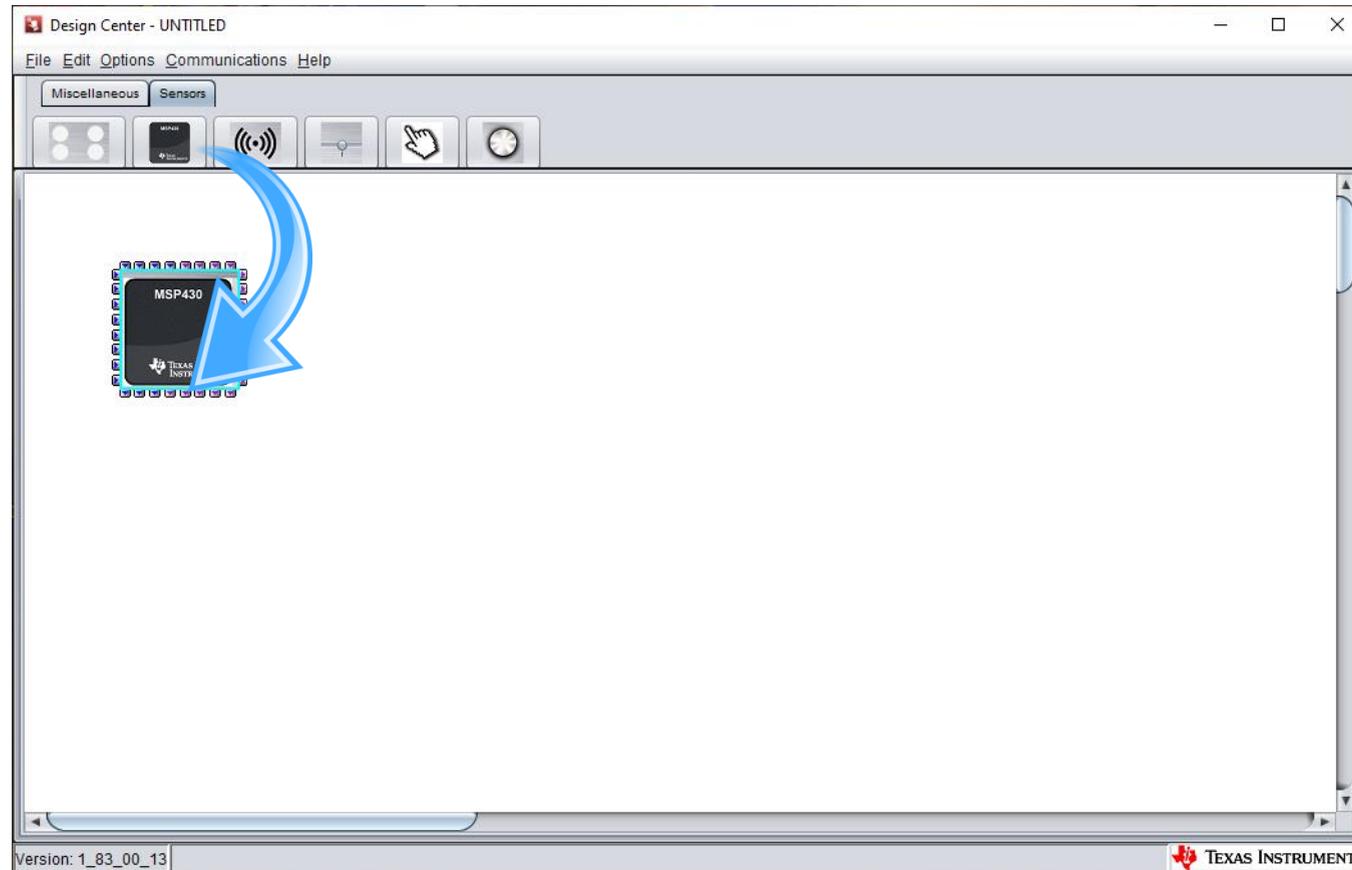
Automating Sensor Designs

CapTivate Design Center

OpenSCAD Demo

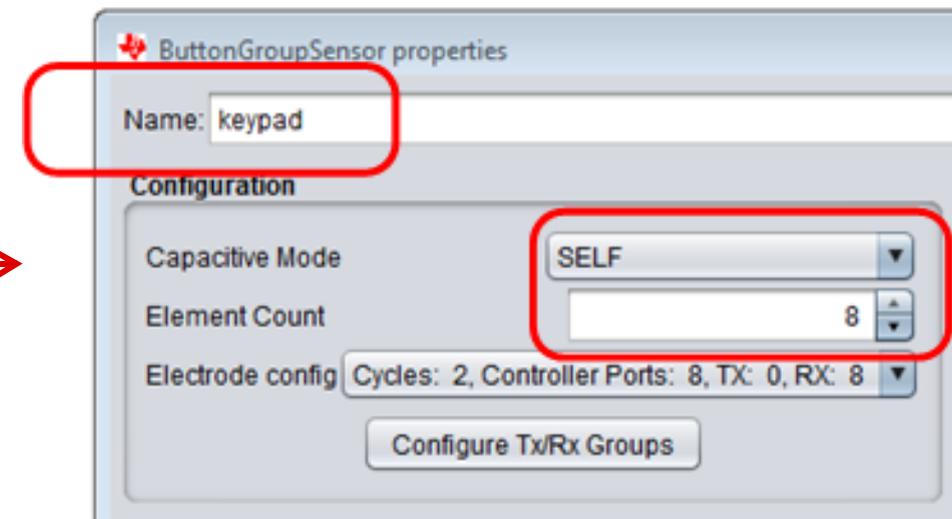
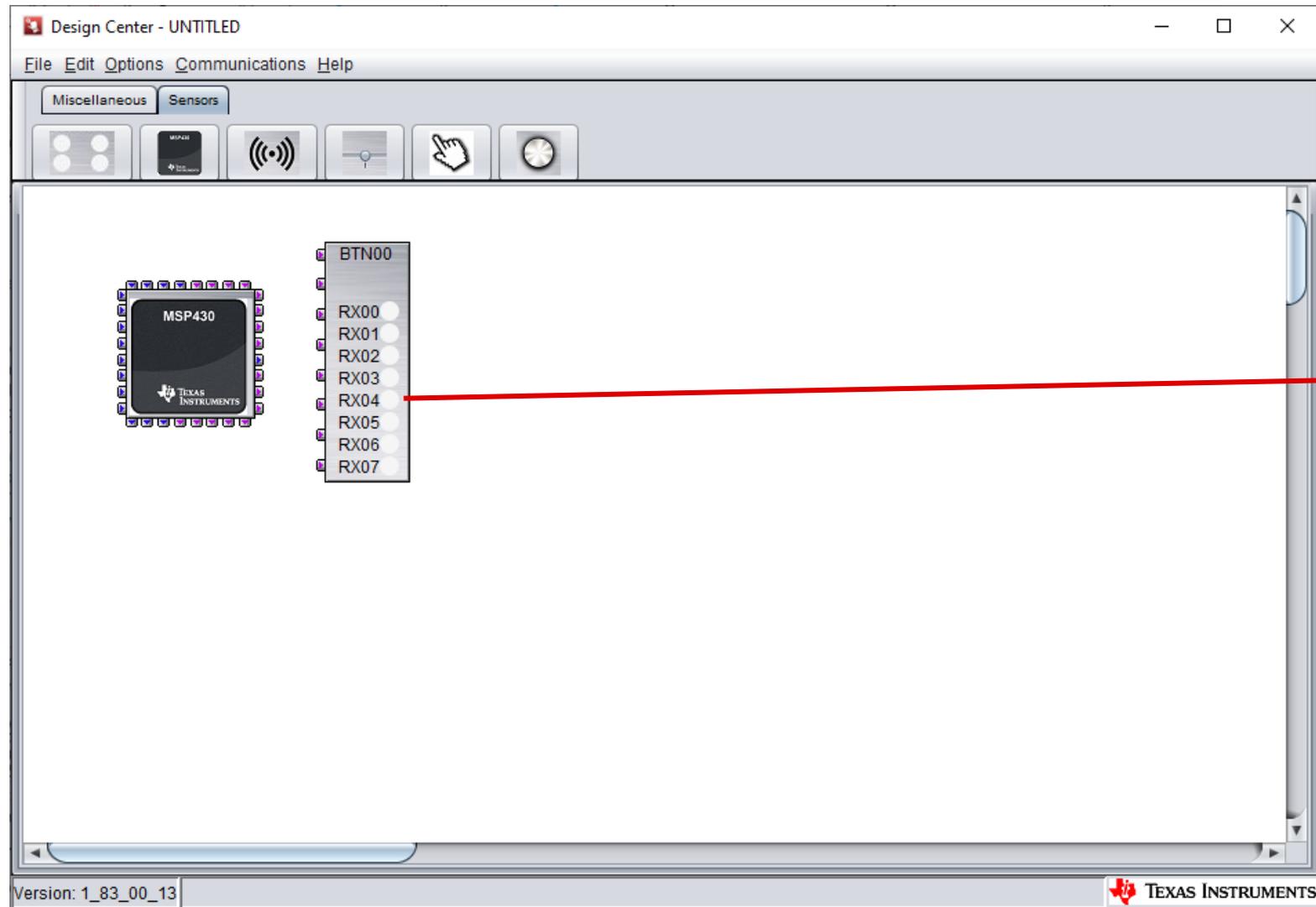
CapTivate Design Center GUI

- Select MCU



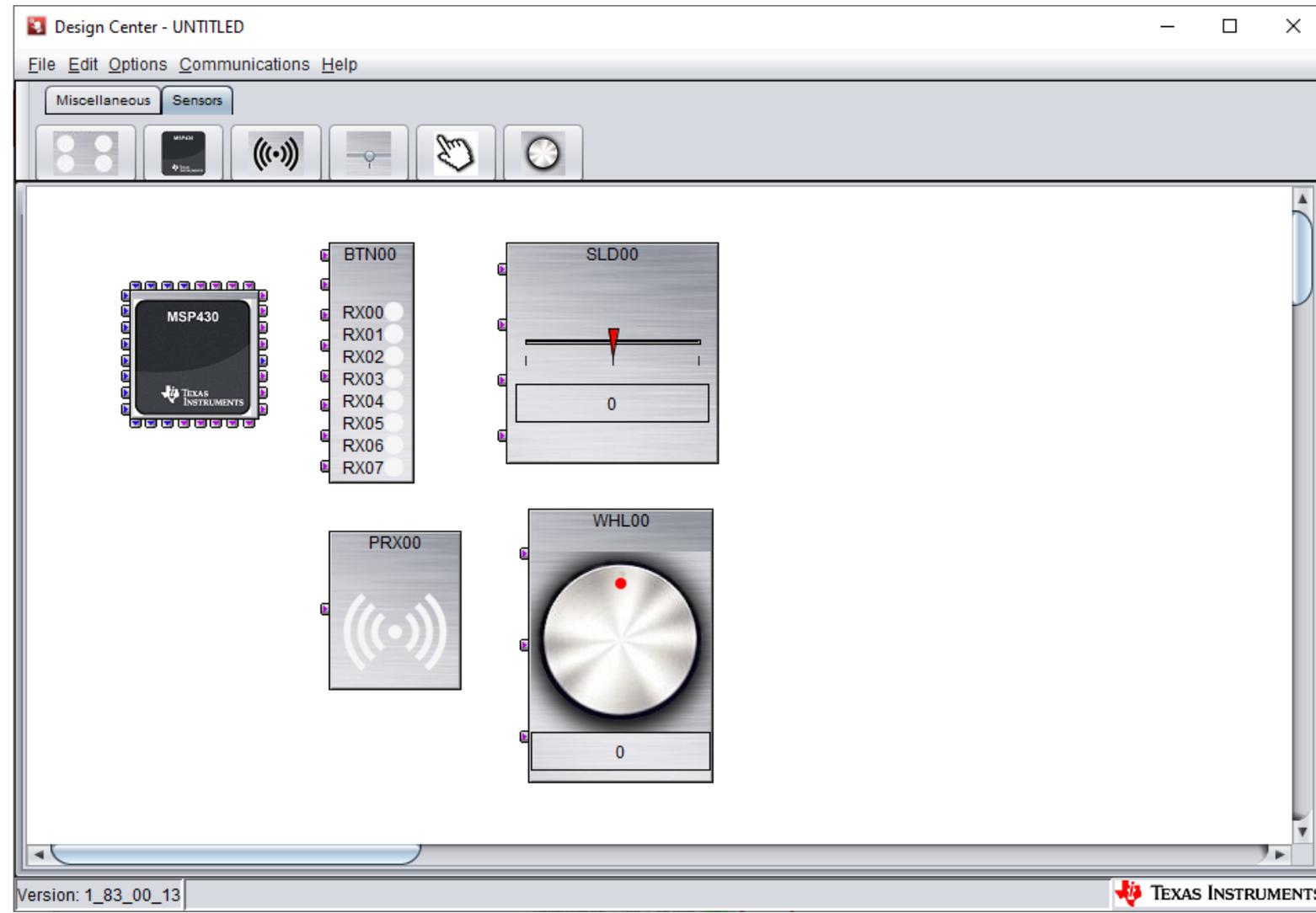
CapTivate Design Center GUI

- Select and configure keypad sensor



CapTivate Design Center GUI

- Repeat for all sensors



CapTivate Design Center GUI

Controller properties

Name: MSP430FR2633IRHB

Configuration
Device: MSP430FR2633IRHB
[Show Device Documentation](#)
Operating Condition: 0C

Compile Time Options
Wake On Proximity Sensor: None

Low Power Mode Options
Low Power Mode: LPM0
[Force LPM4 in Wake-on-Prox Mode](#)

Target Communications
Connected:
Data Logging:
Communication Interface: UART

Configure Connections | Scan Time Estimate | Channel Bar Chart | Channel Table | Conversion_Control | Noise Immunity

Generate Source code | Clear | **Auto-Assign** | Errors

Unconnected		Controller						
Sensor	Electrode	Port	Use Mode	Parallel Gro...	BTN00	PRX00	SLD00	WHL00
BTN00	RX00	CAP0.0	Unrestricted	B0				
BTN00	RX01	CAP0.1	Unrestricted	B1				
BTN00	RX02	CAP0.2	Unrestricted	B2				
BTN00	RX03	CAP0.3	Unrestricted	B3				
BTN00	RX04	CAP1.0	Unrestricted	B0				
BTN00	RX05	CAP1.1	Unrestricted	B1				
BTN00	RX06	CAP1.2	Unrestricted	B2				
BTN00	RX07	CAP1.3	Unrestricted	B3				
PRX00	RX00	CAP2.0	Unrestricted	B0				
SLD00	RX00	CAP2.1	Unrestricted	B1				
SLD00	RX01	CAP2.2	Unrestricted	B2				
SLD00	RX02	CAP2.3	Unrestricted	B3				
SLD00	RX03	CAP3.0	Unrestricted	B0				
WHL00	RX00	CAP3.1	Unrestricted	B1				
WHL00	RX01	CAP3.2	Unrestricted	B2				
WHL00	RX02	CAP3.3	Unrestricted	B3				

Time Cycles

OK

CapTivate Design Center GUI

- Configuration MCU connections to sensors
- Generate MSP430 starter project firmware

Generates 100% of the code to get started.
(no need to write code)

The screenshot shows the 'Controller properties' dialog box for an MSP430FR2633IRHB. It includes sections for Configuration, Compile Time Options, Low Power Mode Options, and Target Communications. Below these are several tabs: 'Configure Connections', 'Scan Time Estimate', 'Channel Bar Chart', 'Channel Table', 'Conversion_Control', and 'Noise Immunity'. A red box highlights the 'Generate Source code' button in the 'Conversion_Control' tab. An arrow points from this button to a larger, detailed view of the button area on the right. Below the tabs is a table for sensor connections and a 'Time Cycles' table.

Unconnected			Sensors				Time Cycles						
Sensor	Electrode	Port	Controller Use Mode	Parallel Gro...	BTN00	PRX00	SLD00	WHL00	BTN00_C00	BTN00_C01	PRX00_C00	SLD00_C00	WHL00_C00
CAP0.0			Unrestricted	B0	RX00				E00				
CAP0.1			Unrestricted	B1	RX04					E04			
CAP0.2			Unrestricted	B2			RX00					E00	
CAP0.3			Unrestricted	B3				RX00					E00
CAP1.0			Unrestricted	B0	RX01				E01			E01	
CAP1.1			Unrestricted	B1	RX05					E05			
CAP1.2			Unrestricted	B2			RX01		E02			E02	
CAP1.3			Unrestricted	B3				RX01					E01
CAP2.0			Unrestricted	B0	RX02				E02			E02	
CAP2.1			Unrestricted	B1	RX06					E06			
CAP2.2			Unrestricted	B2			RX02		E03			E03	
CAP2.3			Unrestricted	B3				RX02					E02
CAP3.0			Unrestricted	B0	RX03				E03			E03	
CAP3.1			Unrestricted	B1	RX07					E07			
CAP3.2			Unrestricted	B2			RX03						
CAP3.3			Unrestricted	B3			RX00					E00	

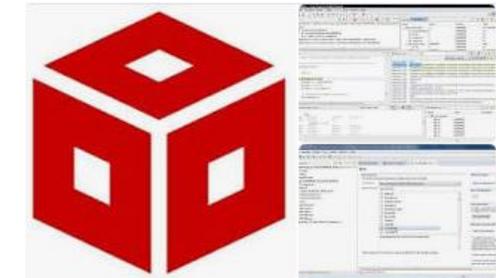
A close-up of the 'Generate Source code' button, which is highlighted with a red box. Other buttons visible are 'Clear', 'Auto-Assign', and 'OK'. The text 'Time Cycles' is visible below the buttons.

The 'Settings' dialog box shows options for project configuration. It has a title bar with a close button (X). The main text is 'Select configuration'. There are two radio buttons: 'Create new project' (which is selected) and 'Update existing project'. At the bottom are 'OK' and 'CANCEL' buttons.

CapTivate Design Center GUI

- Build and program MSP430

```
CAPT_Manager.c  CAPT_HAL.c  CAPT_HAL.h  main.c  I2CSla
55 #include "driverlib.h"           // MSPWare Driver Library
56 #include "captive.h"             // CapTivate Touch Software
57 #include "CAPT_App.h"            // CapTivate Application Co
58 #include "CAPT_BSP.h"            // CapTivate EVM Board Supp
59
60 //*****
61 // Function Implementations
62 //*****
63
64 void main(void)
65 {
66     //
67     // Initialize the MCU
68     // BSP_configureMCU() sets up the device IO and clocking
69     // The global interrupt enable is set to allow peripherals
70     // to wake the MCU.
71     //
72     WDTCTL = WDTPW | WDTHOLD;
73     BSP_configureMCU();
74     __bis_SR_register(GIE);
75
76     //
77     // Start the CapTivate application
78     //
79     CAPT_appStart();
80
81     //
82     // Background Loop
83     //
84     while(1)
```



Code Composer Studio



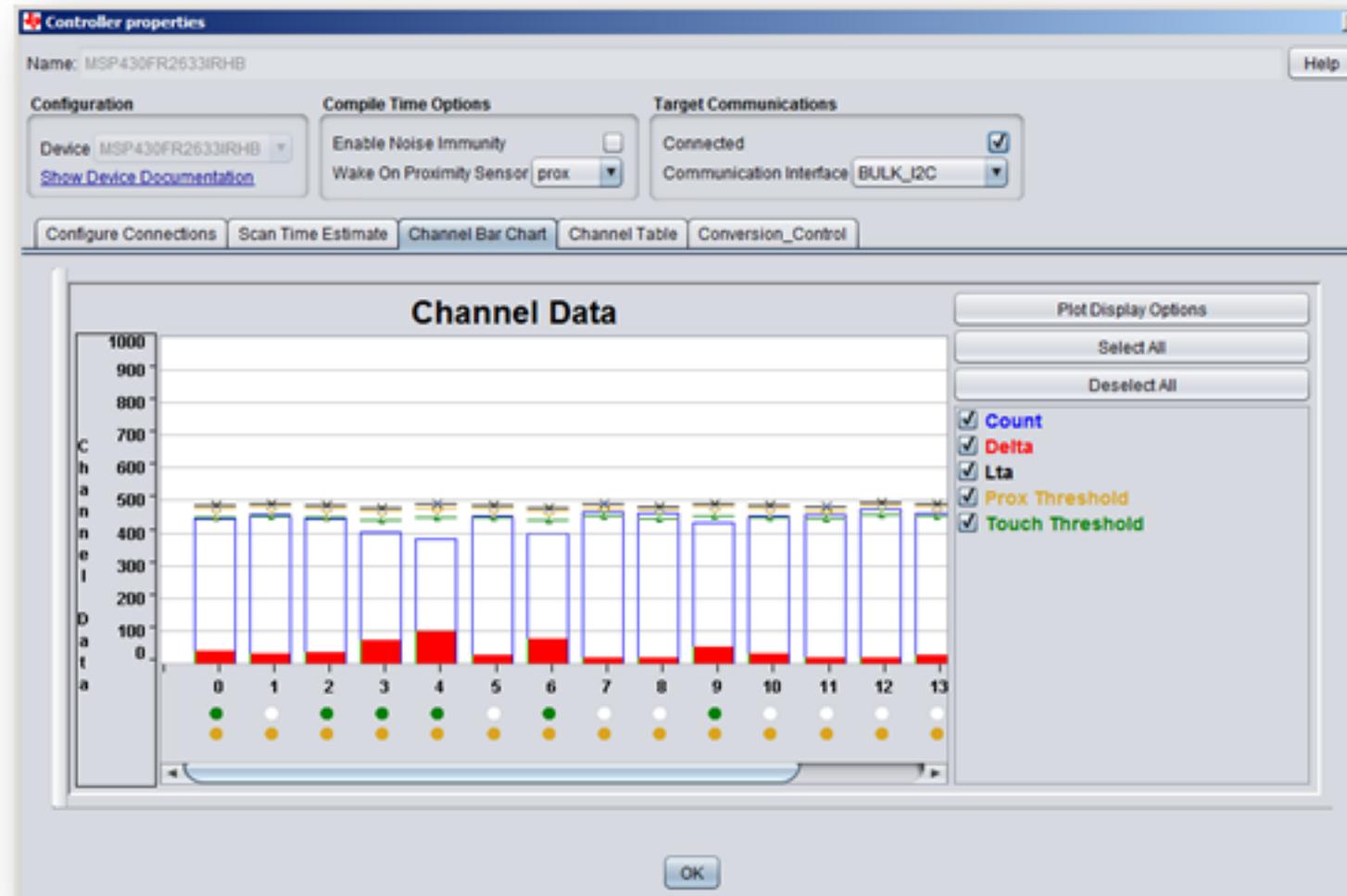
CapTivate Design Center GUI

- Enable communications
- View sensor data

The screenshot displays the 'Controller properties' window for an MSP430FR2633IRHB device. The 'Target Communications' section is highlighted with a red box and a red arrow pointing to a magnified view on the right. In this view, the 'Connected' checkbox is checked, 'Data Logging' is unchecked, and the 'Communication Interface' is set to 'BULK_I2C'. Below the settings, the 'Channel Data' plot shows a series of data points for channels 0 through 13. The plot includes a 'Plot Display Options' panel with checkboxes for 'Count', 'Delta', 'Lta', 'Prox Threshold', and 'Touch Threshold', all of which are checked. The 'Channel Data' plot shows a series of data points for channels 0 through 13, with values ranging from approximately 0 to 500. The plot includes a 'Plot Display Options' panel with checkboxes for 'Count', 'Delta', 'Lta', 'Prox Threshold', and 'Touch Threshold', all of which are checked.

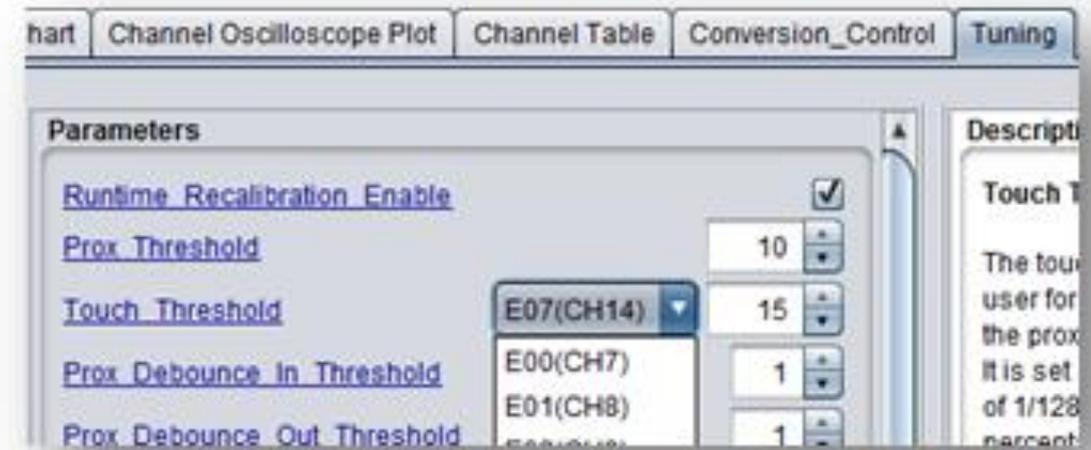
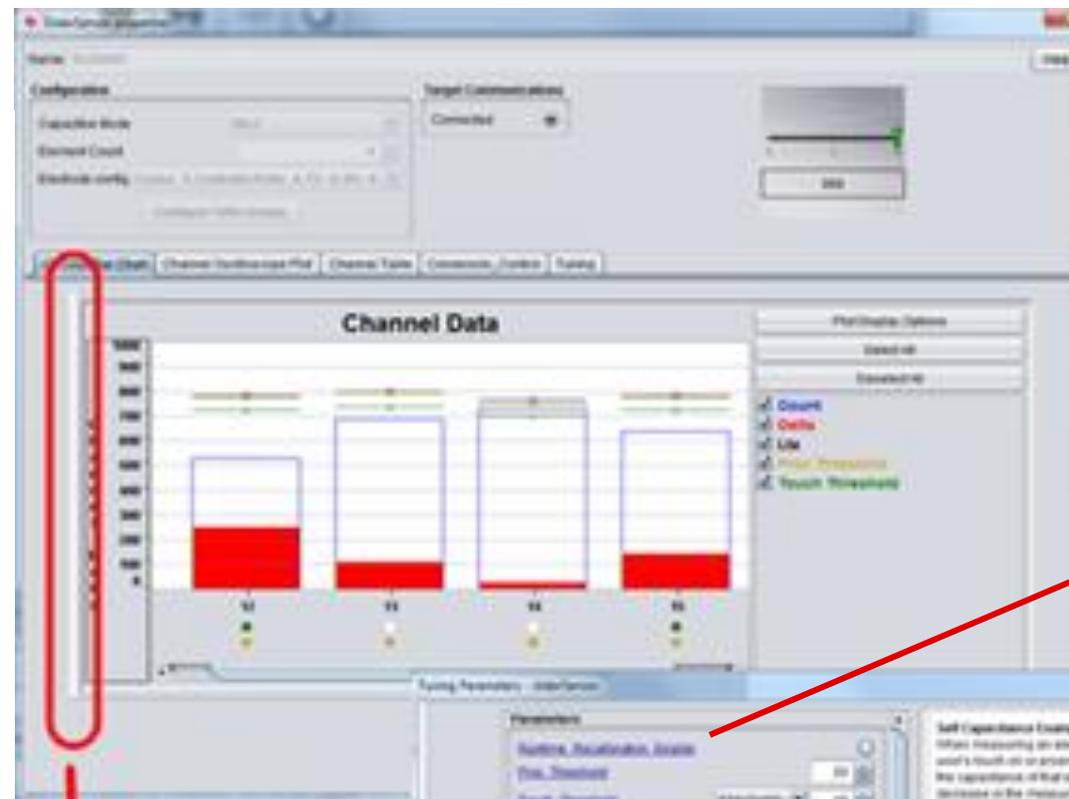
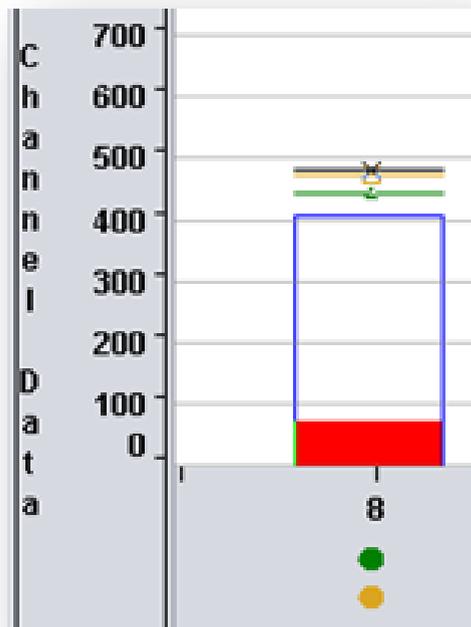
CapTivate Design Center GUI

- View sensor output

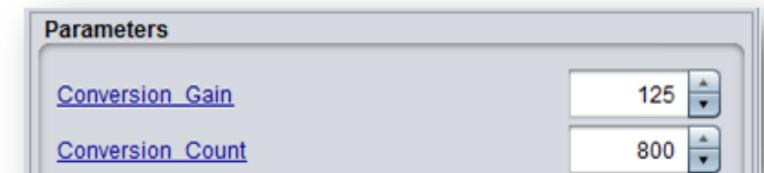


CapTivate Design Center GUI

- Tune sensor's sensitivity and thresholds



Detachable



CapTivate Design Center GUI

- Generate final code

The screenshot shows the 'Controller properties' dialog box for an MSP430FR2633IRHB device. The 'Configuration' section includes options for Device, Operating Condition, and Show Device Documentation. The 'Compile Time Options' section has 'Wake On Proximity Sensor' set to None. The 'Low Power Mode Options' section has 'Low Power Mode' set to LPM0 and 'Force LPM4 in Wake-on-Prox Mode' unchecked. The 'Target Communications' section has 'Connected' and 'Data Logging' unchecked, and 'Communication Interface' set to UART. A red box highlights the 'Generate Source code' button in the bottom right corner of the dialog.

Unconnected Sensor			Controller				Sensors				Time Cycles				
Sensor	Electrode	Port	Use Mode	Parallel Gro...	BTN00	PRX00	SLD00	WHL00	BTN00_C00	BTN00_C01	PRX00_C00	SLD00_C00	WHL00_C00		
CAP0.0			Unrestricted	B0	RX00				E00						
CAP0.1			Unrestricted	B1	RX04					E04					
CAP0.2			Unrestricted	B2			RX00					E00	E00		
CAP0.3			Unrestricted	B3				RX00							
CAP1.0			Unrestricted	B0	RX01				E01			E01			
CAP1.1			Unrestricted	B1	RX05					E05					
CAP1.2			Unrestricted	B2			RX01					E01	E01		
CAP1.3			Unrestricted	B3				RX01							
CAP2.0			Unrestricted	B0	RX02				E02			E02			
CAP2.1			Unrestricted	B1	RX06					E06					
CAP2.2			Unrestricted	B2			RX02					E02	E02		
CAP2.3			Unrestricted	B3				RX02							
CAP3.0			Unrestricted	B0	RX03				E03			E03			
CAP3.1			Unrestricted	B1	RX07					E07					
CAP3.2			Unrestricted	B2			RX03					E03			
CAP3.3			Unrestricted	B3		RX00					E00				

A close-up view of the 'Generate Source code' button, which is highlighted with a red box. Other buttons visible include 'Clear', 'Auto-Assign', and 'OK'. The text 'Time Cycles' is visible below the buttons.

The 'Settings' dialog box is shown, with the 'Update existing project' option selected. The 'Create new project' option is also visible. The 'OK' and 'CANCEL' buttons are at the bottom.

Agenda

CapTivate™ Technology

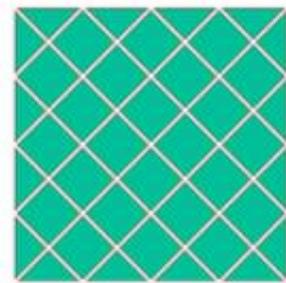
Automating Sensor Designs

CapTivate Design Center

OpenSCAD Demo

Design Touchpad using OpenSCAD

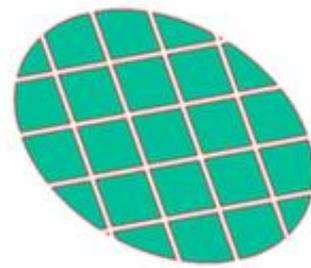
- Touchpad is a 2D sensor
- Remote Controls, headphones, earbuds
- Use OpenSCAD to generate diamond patterns



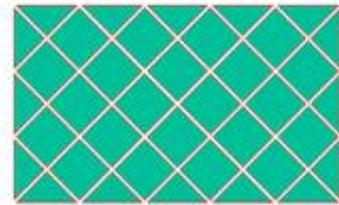
4x4 Square



4x4 Circular



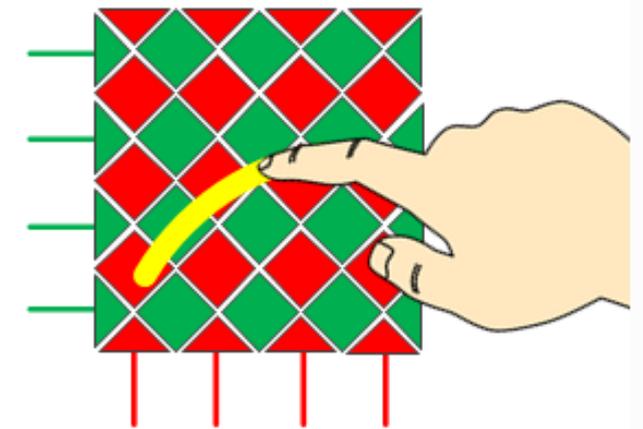
3x4 Rotated Custom



3x5 Rectangular



1x8 1D Slider



- OpenSCAD Demos



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