

Water Flow Meter

This getting started guide reviews the contents of the [MSP430FR6047 ultrasonic sensing evaluation module](#) and tells you how to quickly get started with the MSP430FR6047 device for a water flow meter solution. The information in this guide also applies to the MSP430FR600x and [MSP430FR6043 ultrasonic sensing evaluation module](#) when used in the water metering configuration. For more information on the EVM430-FR6043 in water metering configuration, see the [Optimized ultrasonic sensing metrology reference design for water flow measurement](#).

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1 Introduction

Thank you for requesting the MSP430FR6047 sample kit. This getting started guide reviews the contents of your kit and provides an overview on how to quickly get started with the MSP430FR6047 experimental device for water flow meter solution.

1.1 Package Contents

The package includes:

- a. USS evaluation module (EVM) version 2.0 hardware that has the MSP430FR6047 device with interfaces to a transducer pair: <http://www.ti.com/tool/EVM430-FR6047>
- b. The graphical user interface (GUI) to control the configurable parameters of the transducers and view the results including the delta time of flight (dToF), absolute time of flight (aToF), measured flow rate, and ADC waveforms: http://software-dl.ti.com/msp430/msp430_public_sw/mcu/msp430/USSSWLib/USSSWLibWater/latest/index_FDS.html
- c. An application example project that is supported by Code Composer Studio™ IDE (CCS) or IAR Embedded Workbench® IDE. This project uses TI's Ultrasonic Sensing Solution (USS) Library and interfaces to the GUI: http://software-dl.ti.com/msp430/msp430_public_sw/mcu/msp430/USSSWLib/USSSWLibWater/latest/index_FDS.html
- d. The USS library and supporting documentation of the APIs that are available in the library: http://software-dl.ti.com/msp430/msp430_public_sw/mcu/msp430/USSSWLib/USSSWLibWater/latest/index_FDS.html

1.2 What is Not Included

An Audiowell flow sensor with brass pipe is used as an example in this document. This sensor is available from the [Audiowell Electronics website](#).

1.3 System Requirement

The system requires the latest Java and Uniflash standalone flash tool. If not already installed, they are available from <https://java.com/en/download/> and <http://www.ti.com/tool/UNIFLASH>, respectively

2 Connect the EVM to the Flow Meter

This section describes the hardware connections. For more details of hardware connections, see the [EVM430-FR6047 Hardware Guide](#).

1. Connect the EVM430-FR6047 to the flow meter (see [Figure 1](#)).

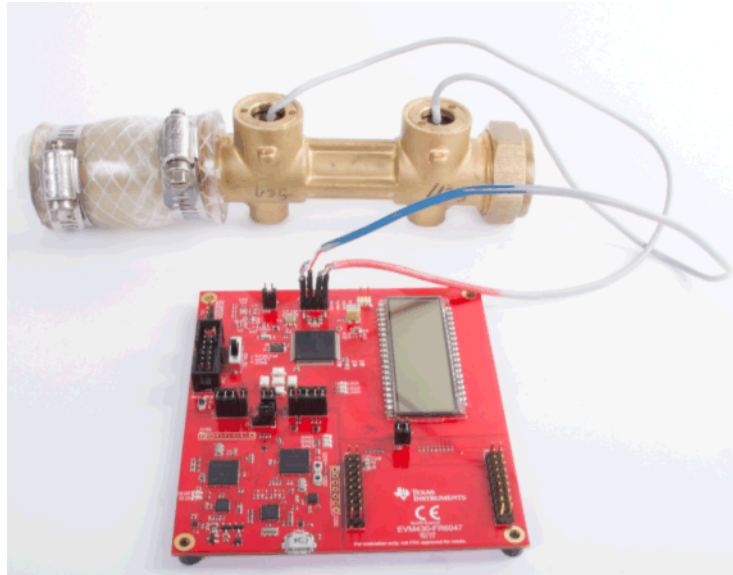


Figure 1. EVM430-FR6047 Connected to Flow Meter

2. Connect the jumpers as shown in [Figure 2](#). The COMM_IRQ, COMM_SDA, and COMM_SCL jumpers on the J5 header are required for communication with the GUI. TEST and RST jumpers on J2 are required to program the board. The POW_SEL switch should be in the middle position (ezFET), J1 in the right position, and both J3 jumpers set to use USB power. The jumper locations are highlighted in [Figure 2](#).

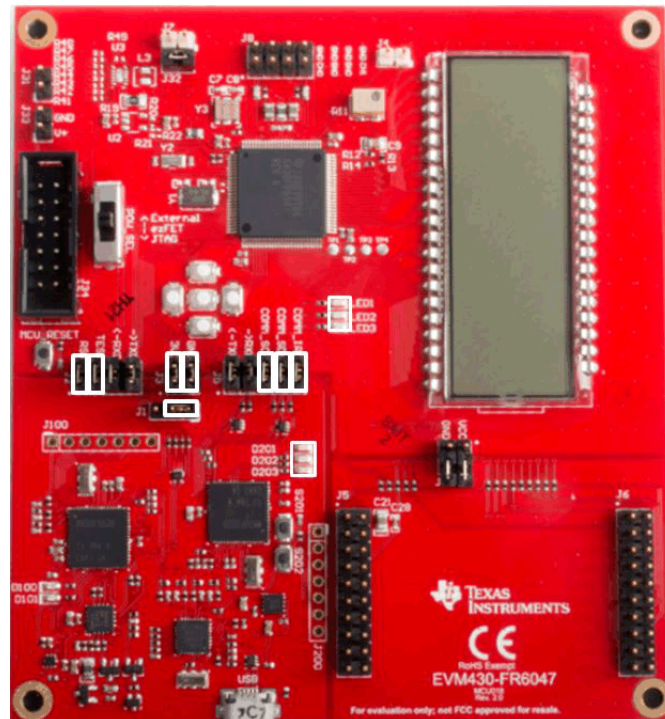


Figure 2. EVM430-FR6047 Jumper Settings

3. Make sure that there is water in the flow meter.
4. Connect a USB cable from the PC to the EVM and verify that LED D201 (power good) is illuminated and LED D202(HID enumeration) blinks on the EVM.

NOTE: If LED3 is lit, this indicates an error. Connecting to the GUI will show the error in the errors tab. If the error is "No signal detected in up and downstream channel", refer to [Section 4.3](#) to ensure a proper signal is obtained.

5. More details on hardware configuration can be found in the [Ultrasonic Sensing Metrology Subsystem Reference Design for Water Flow Measurement design guide](#) and an overview video at [Getting Started with the MSP430FR6047 Ultrasonic sensing EVM](#).

3 Flashing the EVM and Installing the GUI

After you connect the EVM to the PC, flash the latest version of the water metering software to the EVM. You can use the [Uniflash tool](#) to flash the EVM.

1. Install the [Uniflash tool](#) on your PC.
2. Install the latest water metering firmware, which can be downloaded from http://software-dl.ti.com/msp430/msp430_public_sw/mcu/msp430/USSSWLib/USSSWLibWater/latest/index_FDS.html
3. Open Uniflash and select the MSP430FR6047 device.

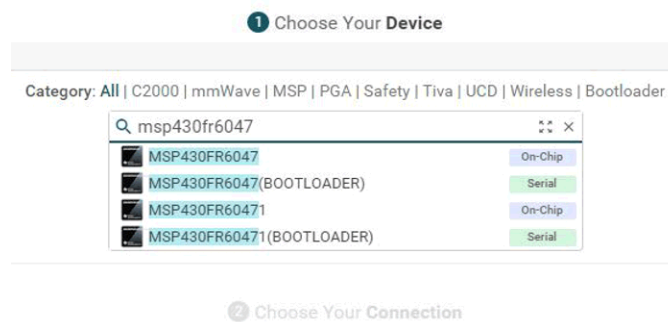


Figure 3. Select MSP430FR6047 Device

4. Choose Connection.
5. Choose image to load. Default image is installed in C:\ti\msp\UltrasonicWaterFR604x_revision_number\image
6. Click Load Image.

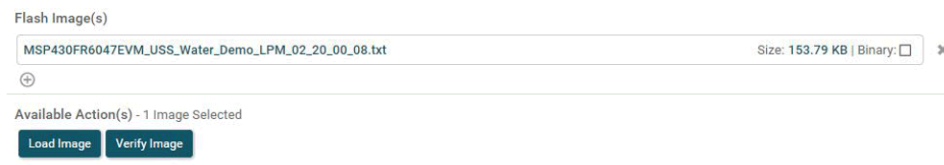


Figure 4. Load Image

7. Install the Ultrasonic Sensing Design Center GUI, which can be downloaded from http://software-dl.ti.com/msp430/msp430_public_sw/mcu/msp430/USSSWLib/USSSWLibWater/latest/index_FDS.html
A shortcut named USS is installed to the Texas Instruments folder in the Windows Start menu to launch the Ultrasonic Sensing Design Center GUI.

4 USS GUI

4.1 Connecting to the Platform

After you have installed the GUI and flashed the image to the EVM, run the USS GUI. Connect to the platform by clicking "Connect" in the "Communications" menu. The GUI reports the connection as shown in Figure 5.

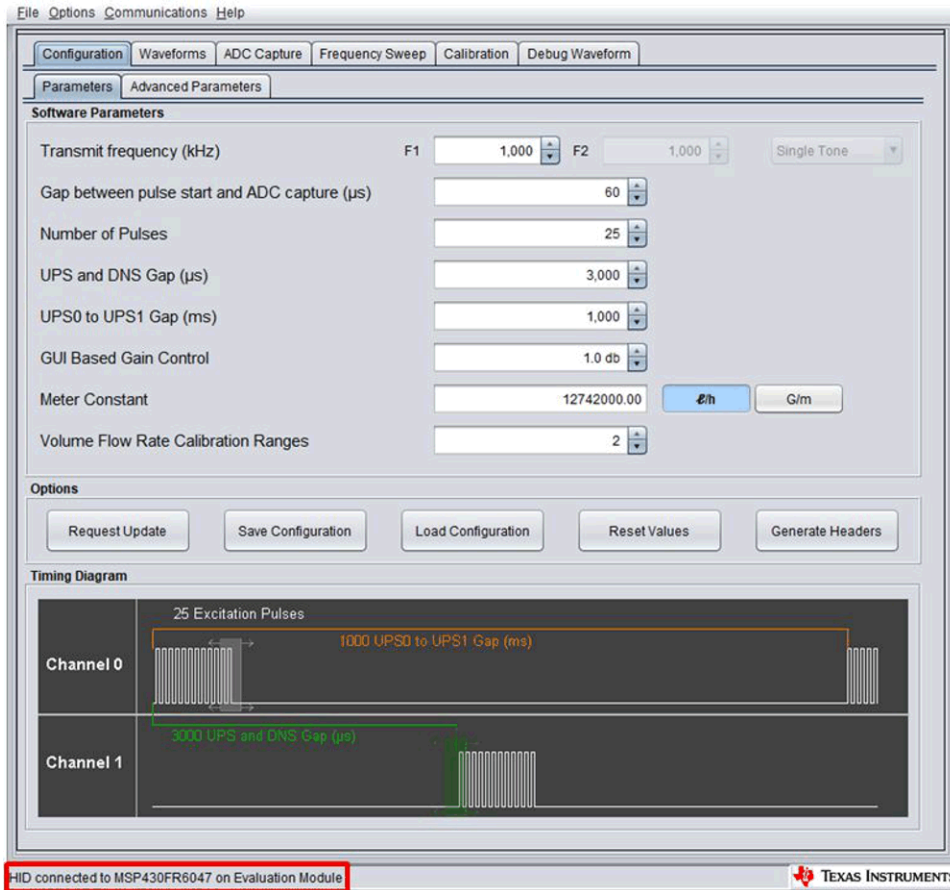


Figure 5. USS GUI Connected to EVM

4.2 Configuration Parameters

4.2.1 Basic Configuration Parameters

Figure 6 shows the primary configuration parameters.

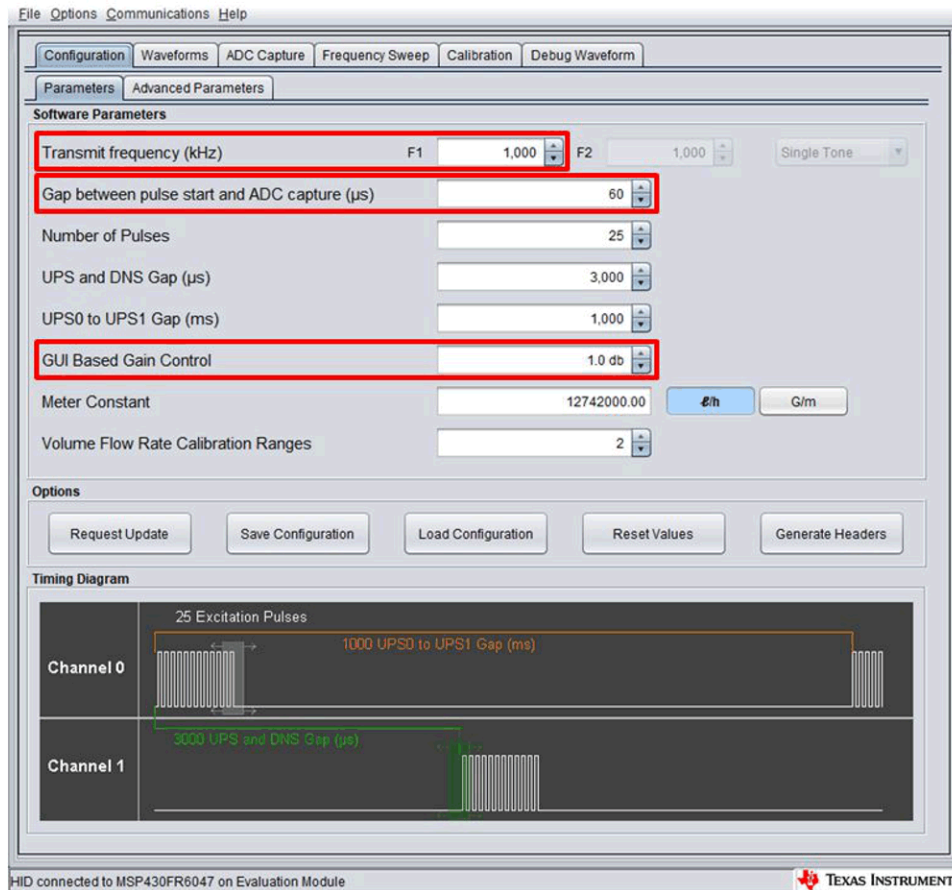


Figure 6. Parameters Tab

The F1, Gap, and Gain parameters are the only parameters which should be initially adjusted. All other parameters should be set to their default values for 1-MHz transducers. These parameters control the excitation, amplification, and ADC capture time between the ultrasonic transducers connected to the platform.

Set the "Transmit Frequency" to the nominal frequency of the transducers in kHz (for example, set to 1000 for 1-MHz transducers). Tune this parameter after the frequency sweep (described in [Section 4.5](#)) is conducted. After the other parameters have been properly determined, tune the transmit frequency to give a better signal response as described in [Section 4.3](#).

Set the "Gap between pulse start and ADC capture" based on the anticipated ultrasonic time of flight for a given flow tube with enough additional capture time to address signal shifts due to temperature variations.

The "GUI Based Gain Control" controls the gain of the integrated PGA. Set this parameter to give an ADC capture of no more than ± 900 ADC counts in the ADC capture tab. Although the system should be operable with signals down to ± 150 ADC counts, setting the gain to give higher ADC counts reduces the standard deviation in measurements.

For example, a DN-25 pipe might have an ultrasonic path which corresponds to a time of flight of approximately 65 μs . This is based on an ultrasonic path between transducers of approximately 9.5 cm and the speed of sound in water (1450 m/s). An appropriate "Gap" that would ensure there is enough time before the signal to accommodate shifts due to temperature variations might therefore be 60 μs . The ultrasonic distance between transducers will affect how much additional margin is required to address shifts in the signal due to temperature and flow variations. For example, a pipe with an ultrasonic path of 19 cm might require 10 μs of additional capture time preceding the signal.

The "Number of Pulses" affects the strength of the signal and the standard deviation of the dToF waveform at zero flow. An increase in the number of pulses should give a lower standard deviation in dToF. There is also a tradeoff with respect to power consumption and interference. As the number of pulses is increased, earlier parts of the excitation signal can interfere with the latter part of the transmitted signal when traveling along alternative ultrasonic paths. The default setting for this parameter should be used as a starting point.

The "UPS and DNS gap" is the time between upstream and downstream measurements. The time required between measurements is governed by the ultrasonic propagation time. Larger pipes require a larger gap. There also needs to be enough time between UPS and DNS excitations to ensure the DNS signal does not have interference from residual reflections of the UPS signal. The default setting for this parameter should be used as a starting point.

The "UPS0 to UPS1 Gap" is the time between the end of a set of measurements and the beginning of the next set of measurements. Power consumption is directly affected by the measurement rate. A UPS0 to UPS1 gap of 1 second consumes roughly twice as much power as a UPS0 to UPS1 gap of 2 seconds. The default setting for this parameter should be used as a starting point.

Set the "Meter Constant" to give a volumetric result that is consistent with a reference meter under flow. Specifics on the calibration procedure for determining the meter constant can be found in the "Calibration User's Guide". The default setting for this parameter should be used as a starting point.

After the desired set of configuration parameters has been set, you should click the "Request Update" button to send these parameters to the platform. The "Save Configuration" button will save the current set of parameters to a file. The "Load Configuration" button loads a previously saved set of configuration parameters from a file. The timing diagram for the configuration can be seen at the bottom of the GUI screen (see [Figure 7](#)). The timing diagram represented in this figure is representative and is not exact.

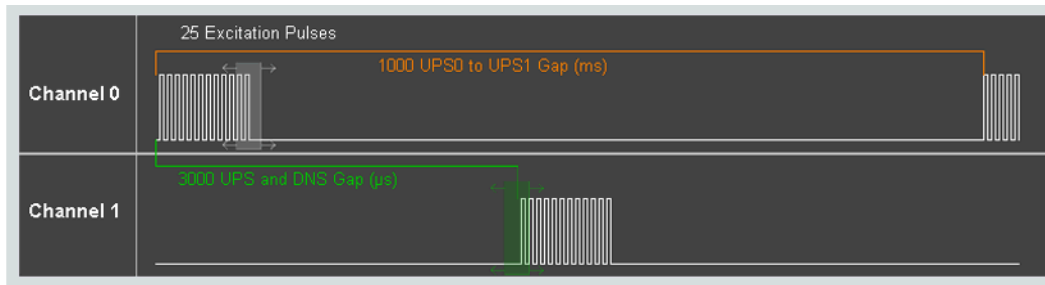


Figure 7. Configuration Timing Diagram

4.2.2 Advanced Configuration Parameters

The "Advanced Parameters" tab provides access to a variety of more advanced configuration parameters (see [Figure 8](#)).

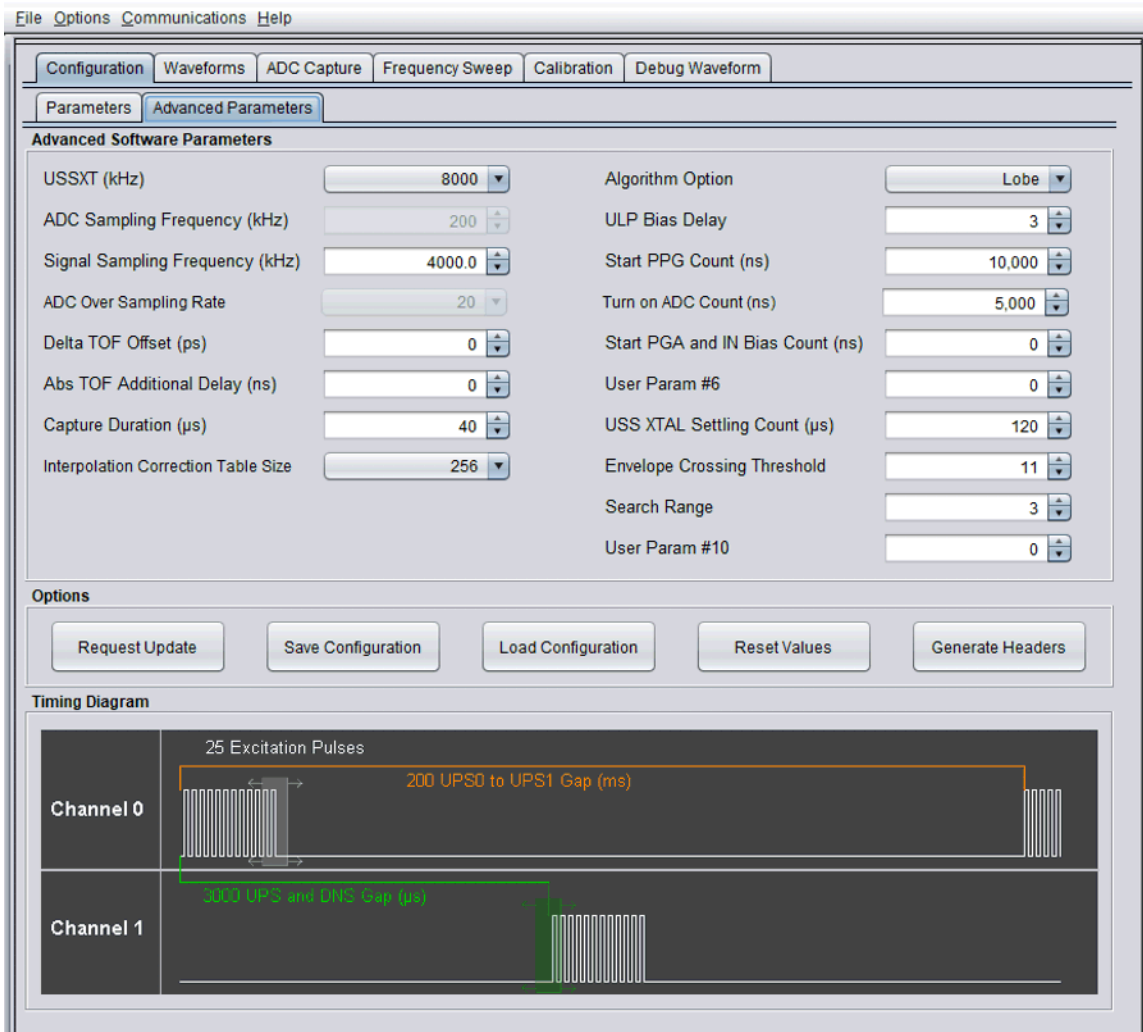


Figure 8. Advanced Parameters Tab

Set the "Signal Sampling Frequency" to 3.6 MHz for 1-MHz transducers and 8 MHz for 2-MHz transducers. Other options including 3.4, 3.8, and 4 MHz can also be used for 1-MHz transducers.

The "Delta ToF Offset" is an adjustment to the differential ToF during the calculation of volume flow rate inside the ultrasonic flow meter library. Developers can optionally make their custom calculation of the volume flow rate based on the ToF values provided by the library. See the "Calibration User's Guide".for more details. The "Abs ToF Additional Delay" is an adjustment to the absolute ToF to account for any additional delays. The value depends on the shape of the signal and the envelope threshold. Developers can optionally set this value to zero and make their own adjustments of the absolute ToF in the application layer.

Increase the "Capture Duration" for configurations with a larger number of pulses, or decrease it for configurations with smaller number of pulses to ensure the signal is fully captured with enough margin for shifts over the intended operating temperature range.

The "Interpolation Correction Table Size" determines the number of points used to correct for the interpolation used in the AbsToF algorithm. Designs requiring more accurate results can use a larger interpolation table. For details on this table, see the "Calibration User's Guide".

The "Algorithm Option" determines which algorithm is used. Only the lobe algorithm is currently available for water metering. A detailed explanation of how this algorithm works can be found in the [Ultrasonic Sensing Metrology Subsystem Reference Design for Water Flow Measurement design guide](#).

The "Envelope Crossing Threshold" determines which lobe the AbsToF algorithm will lock onto. Set this threshold to lock onto the earliest lobe peak that is above the noise. In the example shown in [Figure 9](#), this lobe peak corresponds to a threshold of approximately 22%. Additional information regarding the envelope crossing threshold can be found in the [Optimized ultrasonic sensing metrology reference design for water flow measurement](#).

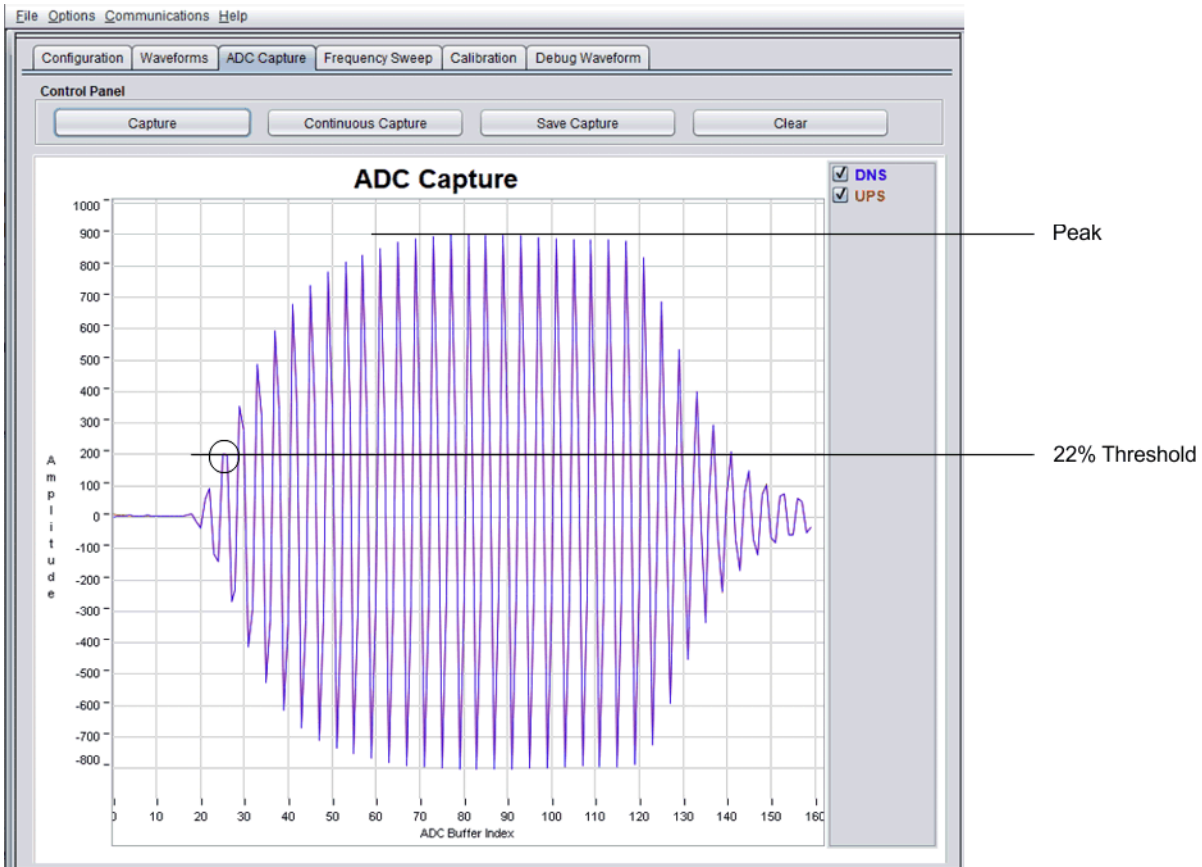


Figure 9. Representative Captured Waveform With Interpolation

The "Search Range" parameter is specific to gas algorithms and is not currently used by the "Lobe" algorithm.

"User Param #6" is reserved for future use.

"User Param #10" is reserved for future use.

4.2.3 Conditional Parameters

Modify the following parameters only under specific conditions.

The "ULP Bias Delay" determines when the bias circuit is turned on. The relevant timing diagrams for the operation of the ULP bias circuit can be found in the [MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide](#). For low current consumption, the recommended value is 3.

The "Start PPG Count" determines when the PPG is started. The timing diagrams for the operation of the ULP bias circuit can be found in the [MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide](#). For low current consumption, the recommended value is 10000 nanoseconds. The only scenario in which this value should be changed is when the time of flight between transducers is less than 30 μ s. Use a corresponding increase in this parameter to enable more closely spaced transducers. For transducers spaced 25 μ s apart, increase this count to 15000 ns.

The "Turn on ADC Count" determines when the ADC is turned on. The relevant timing diagrams for the operation of the ULP bias circuit can be found in the [MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide](#). Do not modify this parameter.

The "Start PGA and IN Bias Count" determines when the PGA and in Bias Circuit is turned on. The relevant timing diagrams for the operation of the ULP bias circuit can be found in the [MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide](#). Do not modify this parameter.

The "USS XTAL Settling Count" determines how much time is allowed for crystal or resonator settling. Based on internal experiments, 120 μ s is suggested for resonators, and 5000 μ s is suggested for crystals.

The "Search Range" parameter is specific to gas algorithms and is not currently used by the "Lobe" algorithm.

4.2.4 Configuration Tuning

After a working configuration has been set, you can experiment with changes to that working set to tune the system for optimum performance and power. [Table 1](#) indicates how changes in specific configuration parameters change system performance.

Table 1. Configuration Tuning

Parameter	Change to Parameter Affects...			
	Power Consumption	Flow Performance	Standard Deviation	Zero Flow Drift
Number of Pulses	✓	✓	✓	✓
UPS0 to UPS1 Gap	✓			
GUI Based Gain Control			✓	✓
Transmit Frequency		✓	✓	✓
Envelope Crossing Threshold		✓		
Capture Duration	✓	✓		✓

4.3 Capturing the ADC Signals

To capture the ADC signal, go to the "ADC Capture" tab and click the "Capture" button. If you are using and AudioWell DN-25 meter, you should see a signal that looks like [Figure 10](#) at zero flow.

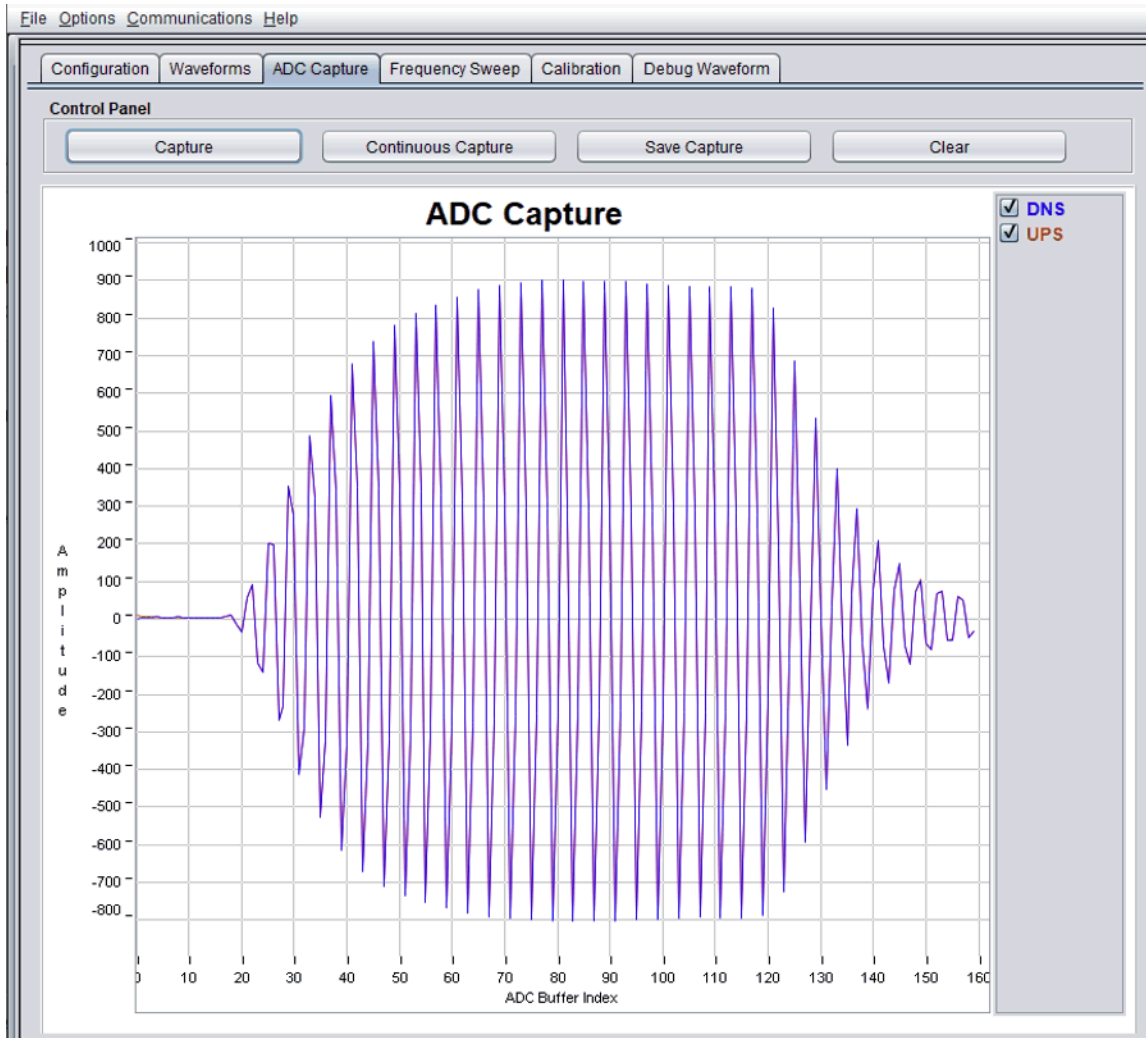


Figure 10. Captured ADC Signal

If the capture looks different, check these items first.

- Reduce the gain in your configuration parameters to -6.5 dB. Because the captured signal is windowed, the tail of the signal may be slightly truncated without changing the results.
- Adjust the Gap between pulse start and ADC capture. [Figure 11](#) shows an example where the gap is set too long. [Figure 12](#) shows an example where the gap is set too short.

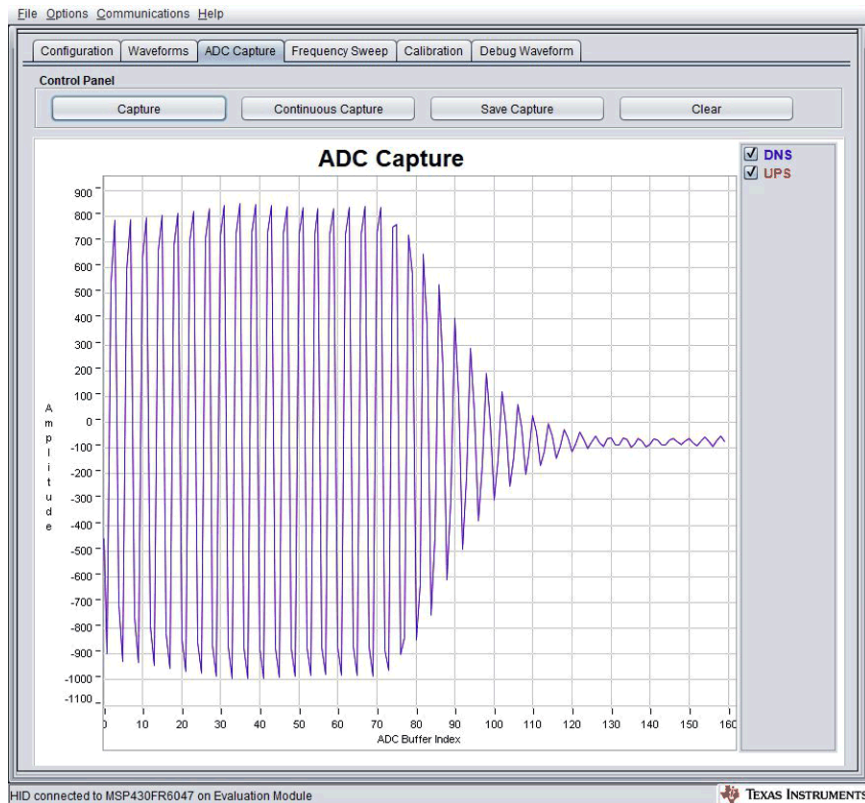


Figure 11. Gap Between Pulse Start and ADC Capture Set Too Long

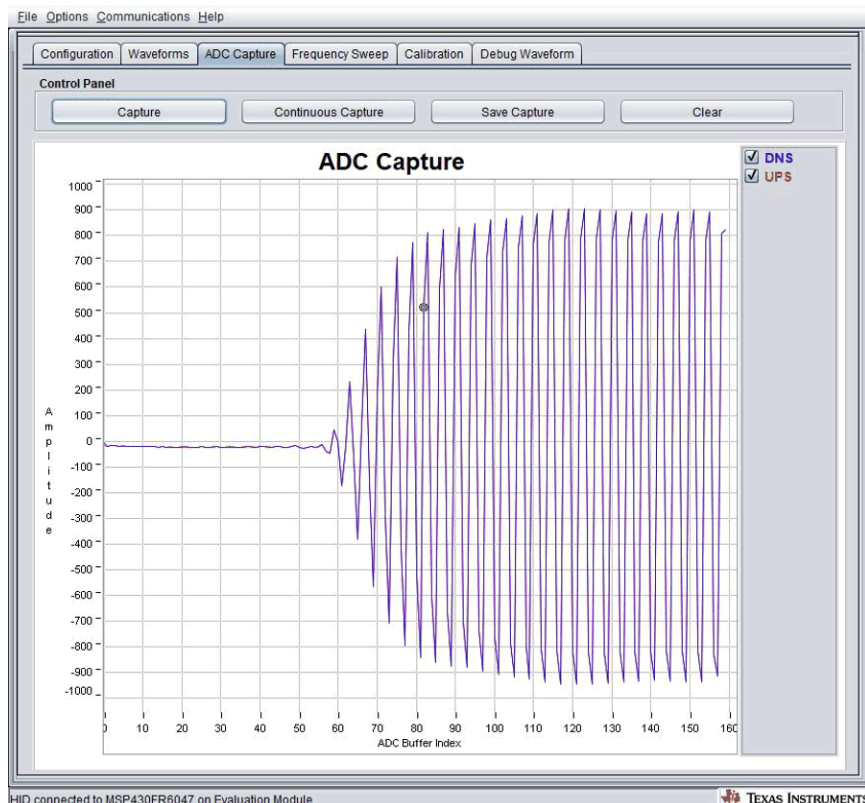


Figure 12. Gap Between Pulse Start and ADC Capture Set Too Short

- If no signal is observed, check the transducer connections to the platform. Connect the transducers as shown in [Section 2](#).
- Be sure that the pipe is filled with water. If no water is in the pipe or the transducers are not connected properly to the EVM, the captured signal may look similar to [Figure 13](#).

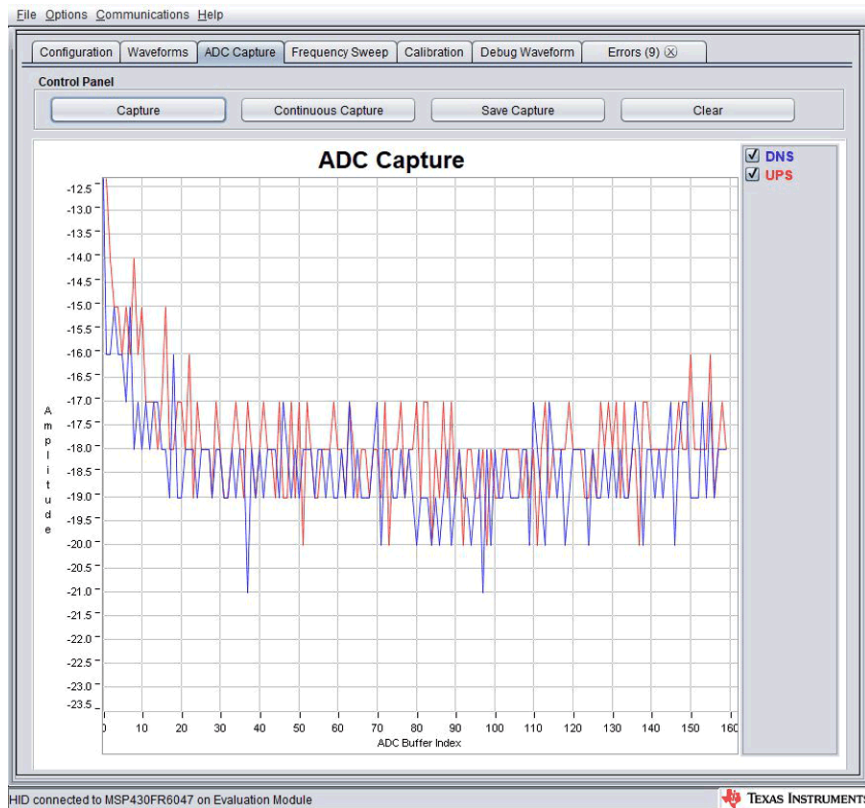


Figure 13. Captured ADC Signal With No Water or Bad Connection

To save the capture, click the "Save Capture" button and provide a filename. To continuously capture to a file, click the "Continuous Capture" button and provide a filename.

4.4 Capturing Waveforms

After you have a good ADC capture, go to the "Waveforms" tab to capture some waveforms. In the "Waveforms" tab, click the "Start" button to start capturing waveforms. The GUI displays the Delta ToF, Absolute ToF, and Volume Flow Rate waveforms (see Figure 14). Real time statistics are also available below each waveform. A typical standard deviation value of Delta ToF can be seen in the red box shown in Figure 14.

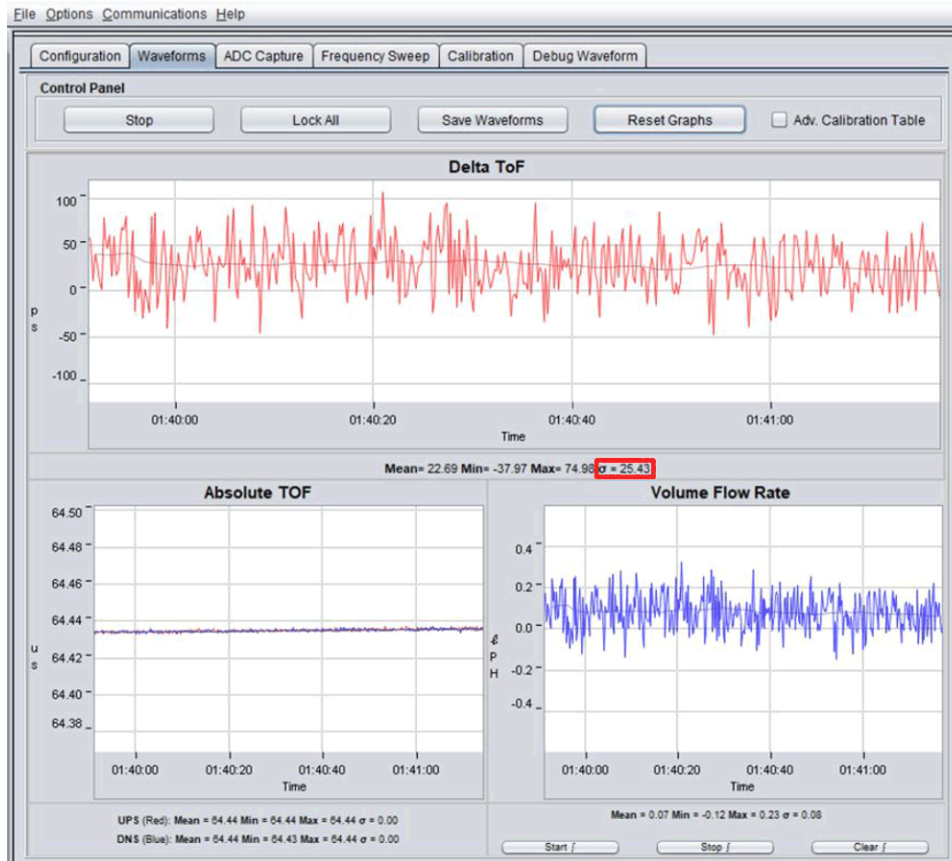


Figure 14. Capturing Waveforms

The frequency of measurement updates can be increased by reducing the "UPS0 to UPS1 Gap" in the "Configuration" tab.

After capturing waveforms for some time, you can save them to a file using the "Save Waveforms" button. The "Lock All" button stops updates, and the "Reset Graphs" button erases all previously captured data.

4.5 Frequency Response

The frequency response of the meter can be determined in the GUI to ensure the excitation frequency is optimal. A "Frequency Sweep" is initiated by first setting the desired starting excitation frequency in the "Configuration" tab. After this has been set, set the number of "Captures" and "Step Size" to cover the band of interest. In [Figure 15](#), the sweep is configured to go from 800 kHz to 1208 kHz. The "Frequency Sweep" button requests a file name and then initiates the sweep.

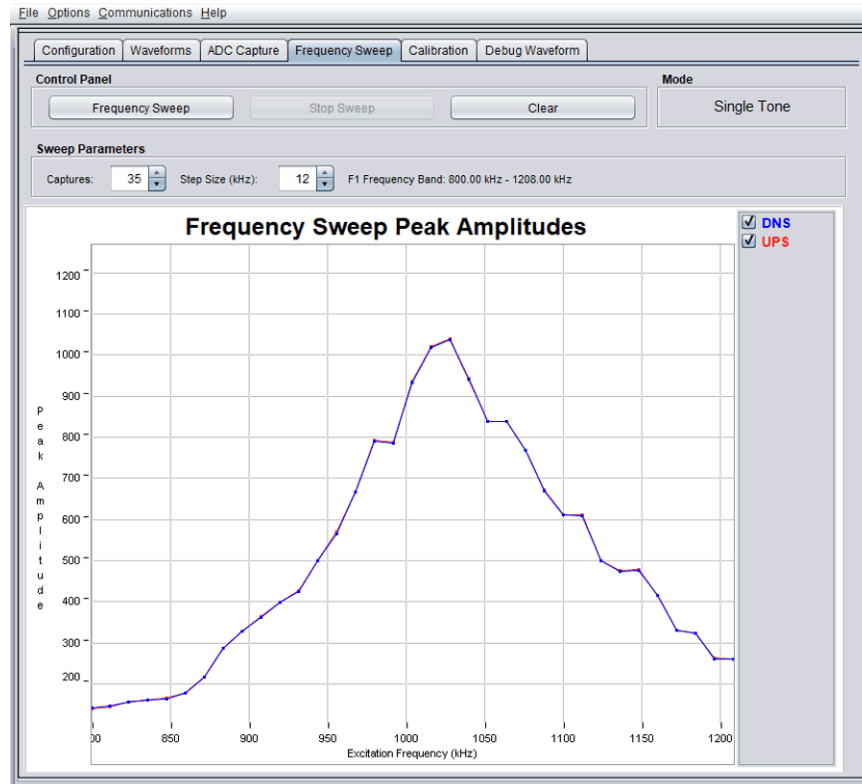


Figure 15. Frequency Sweep Peak Amplitudes

From this sweep, 1020 kHz appears to be a good excitation frequency for this meter. The process for tuning the configuration to an optimal value can be summarized as follows:

NOTE: Steps 1 to 3 should have already been completed in [Section 4.3](#).

1. Set the "Transmit Frequency" to the nominal frequency of the transducer.
2. Adjust the "Gap between pulse start and ADC capture" and "Capture Duration" parameters to capture the complete signal in the "ADC Capture" window.
3. Adjust the "Gain" setting to get a signal which has an amplitude of ± 900 ADC counts.
4. Set the "Transmit Frequency" to a frequency which is 200 kHz less than the nominal frequency of the transducer and conduct a frequency sweep which ends at a frequency 200 kHz greater than the nominal frequency of the transducer.
5. Identify the peak amplitude of the "Frequency Sweep" and set the "Transmit Frequency" to this value.

5 Meter Characterization

Meter characterization comprises standard deviation, zero flow drift, and flow testing.

5.1 Single Shot Standard Deviation

The standard deviation in dToF (and volume) is often used as a measure for the accuracy with which flow measurements can be made. Although it is possible to average across several measurements, the amount of time and power required to do this may not meet application requirements.

Standard deviation testing is typically conducted at room temperature over a period of 30 minutes with a 1 measurement per second rate to ensure a statistically valid average. The standard deviation is reported with the mean in the "Waveform Tab" of the GUI. [Figure 16](#) shows the single-shot STD of blocks of 200 measurements. Each plot represents single-shot STD of 200 measurements. The plot clearly shows the variation of single-shot STD is just ± 2 ps, and the average is < 25 ps.

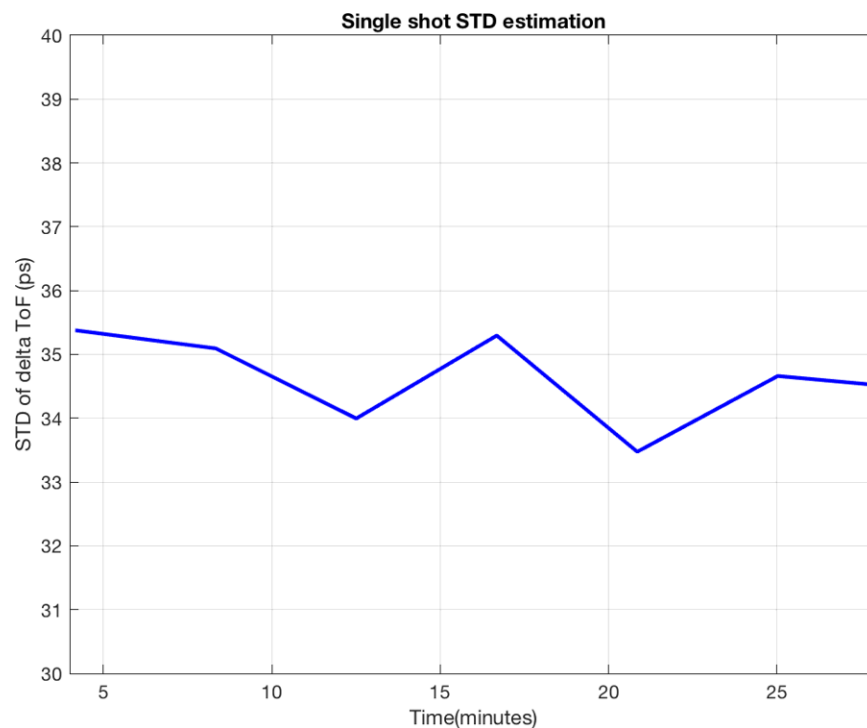


Figure 16. Single Shot Standard Deviation

5.2 Zero Flow Drift Testing

Zero flow drift testing is often used as a measure of the minimum detectable flow of a meter and accuracy in low flow. The minimum detectable flow of a meter is related to the zero flow drift and the sensitivity of the meter. A meter with higher sensitivity and lower zero flow drift will have a smaller minimum detectable flow. The minimum detectable flow is limited by the drift in dToF over temperature. This test is typically conducted in an oven with a temperature profile ranging from 5°C to 85°C over a period of 4 to 24 hours, depending on the robustness of the test. These tests are conducted with both the meter and electronics in the oven as well as with just the meter in the oven to ensure the electronics do not contribute to the drift. More detailed information on zero flow drift testing can be found in the [Ultrasonic Sensing Metrology Subsystem Reference Design for Water Flow Measurement design guide](#).

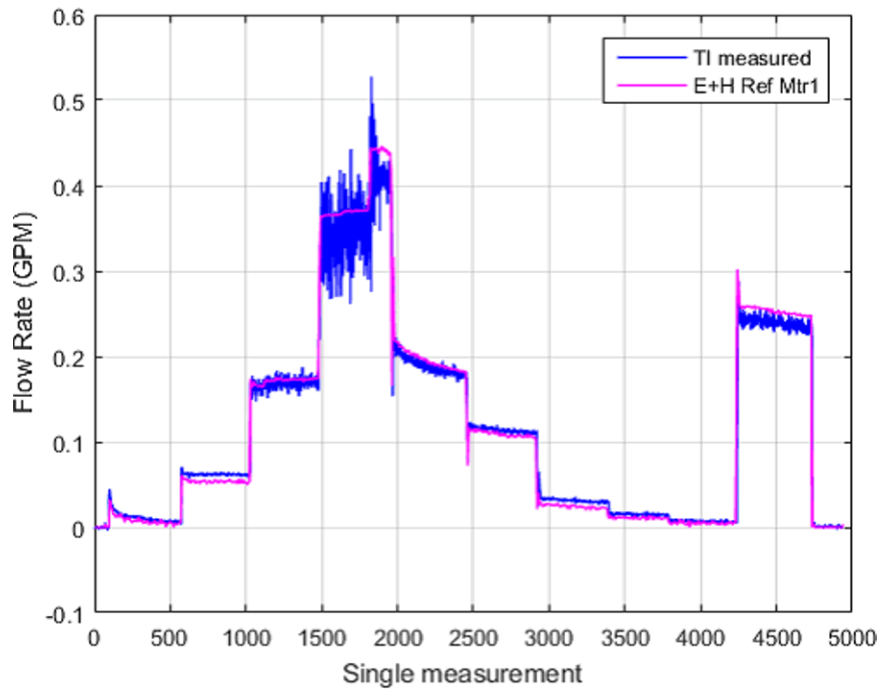
5.3 Flow Testing

Flow testing is typically conducted with a reference meter and a temperature controlled water circulation system. [Figure 17](#) shows a typical flow test setup. This setup includes a large water tank, two reference meters, and a Device Under Test (DUT). Flow is recorded at various flow rates by one of the two reference meters and the DUT. The temperature of the water is varied by addition of ice or hot water to the tank with a thermocouple recording the water temperature. A video discussing flow measurements and setup can be found at [Ultrasonic Water Flow Meter Demonstration](#).



Figure 17. Flow Test Setup

Flows are typically captured over several minutes and averaged to compare accuracies between a reference meter and the DUT. [Figure 18](#) shows comparative flow tests results for a meter at various flow rates.



NOTE: Measurements at room temperature

Figure 18. Audiowell Meter Measurements

For more details on water flow testing, see the [MSP430FR6047 and Ultrasonic Software Based Water Flow Meter Measurement Results](#) application report.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from September 1, 2019 to March 26, 2020 (from * Revision (Sep 2019) to A Revision)	Page
• Added Added "MSP430FR600x" to list of devices covered by this guide	1

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