Application Report

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Frequently asked questions (FAQ) on ultrasonic sensing technology for water and gas flow metering with MSP430FR604x MCUs

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ABSTRACT

This FAQ describes the waveform-based correlation techniques for time-of-flight measurements used in ultrasonic-sensing technology for water flow metering and gas metering. This document describes the design and engineering tradeoffs when designing using the MSP430FR604x microcontrollers (MCUs), software based on the Ultrasonic Design Center, and key performance metrics.

Contents

Trademarks

1 Frequently Asked Questions (FAQ)

This section answers frequently asked questions (FAQs) that arise while using the MSP430FR604x MCUs with the Ultrasonic Design Center software for water and gas flow meters.

1.1 Basic Setup

1. The MSP430 MCUs Ultrasonic Design Center does not recognize the MSP430FR6047 Ultrasonic Sensing Evaluation Module or the MSP430FR6043 Ultrasonic Sensing Gas Evaluation Module. What could be the possible issues?
   - Make sure that the EVM430-FR6047 or EVM-FR6043 is connected to the PC.
   - The EVM includes a HID bridge that should be recognized by Windows Device Manager as two HID devices.
   - Make sure the jumpers are set properly to power the board and to communicate with the HID bridge. Refer to the EVM430-FR6047 Hardware Guide or the EVM430-FR6043 Hardware Guide for more details.
   - Try restarting the GUI.
   - If needed, reprogram the EVM.
   - You can also try resetting the device.

2. The Ultrasonic Design Center GUI is connected, but it is not updating the MSP430 MCU after loading a new configuration. What can cause this behavior?

   Some configurations are not supported by the MCU. If the GUI attempts to load an unsupported configuration to the MCU, the GUI will display an error. For more information about the specific error, refer to the *Error Handling* section of the help in the Ultrasonic Design Center. You might need to use a different configuration or modify the firmware.

   You can also try to flash the MCU again.

3. MSP Flasher, Code Composer Studio™ IDE (CCS), or IAR Embedded Workbench® for MSP430 IDE (IAR EW430) cannot program and debug the EVM.
   - Make sure that the EVM430-FR6047 or EVM430-FR6043 is connected to the PC.
   - The EVM includes eZ-FET circuitry that is used to program and debug the MSP430FR604x MCU. The eZ-FET should be recognized by Windows Device Manager as two HID devices.
   - Drivers are needed for proper operation. TI recommends installing the drivers by installing an IDE such as TI CCS or IAR EW430. Drivers are also available at http://www.ti.com/MSPdrivers.
   - Make sure to set the jumpers properly to power the board and to communicate with eZ-FET. Refer to the EVM430-FR6047 Hardware Guide (or EVM430-FR6043 Hardware Guide) for more details.

4. The ADC Capture panel in the GUI shows negligible (or zero) ADC signal. What are the possible problems?
   - Verify the polarity of the transducers. Make sure the GND of the transducer is connected to the GND and not the SIGNAL pin on the EVM.
   - Adjust the Ultrasonic Sensing Design Center GUI parameters as discussed in the quick start guide.
   - For a water flow meter application, make sure the pipe is filled with water and oriented in a way that the transducers are completely immersed in water. Also, shake the pipe after it is full and observe if there are any air bubbles. Top off with water to refill any area that might have an air bubble.

5. How was the current consumption measured?

   For current consumption measurements, TI used a Keysight N6705B instrument. The test was configured to supply current from the Keysight instrument at 3.3 V, and the instrument was set to sample the current at approximately 200 kHz.

   For water flow meter application, these measurements were done using MSP430FR6047 silicon revision B MCUs and software library version USSSWLib 01_40_00_06. Refer to the *Average Power Consumption* section in Ultrasonic Sensing Subsystem Reference Design for Water Flow Measurement for more information.

   For gas meter application, the measurements were done using MSP430FR6043 silicon revision A MCUs and software library version USSSWLib 02_20_00_09. Refer to the *Average Current Consumption* section in Ultrasonic Sensing Subsystem Reference Design for Gas Flow Measurement for more information.

6. The ADC output waveform signal level is nonexistent. What could be the potential problems?

   For water flow meter applications, make sure that water is in the pipe. If water is present, make sure that the transducers are positioned so that they are immersed in water. A common mistake is to have the pipe upside down so that the transducers are in the air and not immersed in water. The signal is attenuated significantly if it is not propagating through the water. This is a common reason for a very low signal.

   Make sure that the correct transducer excitation frequency is selected. For a nominal frequency of 1 MHz, using an excitation frequency that is 100 kHz away from the correct frequency can cause as much as 15 dB of attenuation in the signal amplitude, and the frequency response can also be significantly worse.

   Similarly, for gas meter applications, the correct transducer frequency needs to be selected. Depending on the medium being air, methane or any other gas, the PGA setting also needs to be configured correctly to make sure that the ADC output is sufficiently large.

7. What does a good ADC output waveform signal look like?

A good signal should have the following characteristics:

- The DC offset should be close to zero.
- For water flow meter applications, the ADC output waveform amplitude should be within ±1000 codes for 1-MHz transducers and ±600 codes for 2-MHz transducers. The gain setting can be controlled by the "GUI Based Gain Control" parameter.
- For gas meter applications, the ADC output waveform amplitude should be within ±1000 codes for transducers at 200 kHz to 500 kHz. The gain setting can be controlled by the "GUI Based Gain Control" parameter.
- "Capture Duration" should be set so that the waveform ramps up and also ramps down. As an example, Figure 13 titled "USS Design Center ADC Waveform Capture Window" in Ultrasonic Sensing Subsystem Reference Design for Water Flow Measurement for water flow meter applications, and in Ultrasonic Sensing Subsystem Reference Design for Gas Flow Measurement for gas meter applications are good templates.
- "Gap between pulse start and ADC capture" should be set so the waveform clearly starts at approximately 0 and ramps up to the signal with the transducer frequency, which can be 1 to 2 MHz for water flow meters and 150 to 500 kHz for gas meters. It is good to make sure that the capture includes a few samples that are close to 0 at the beginning of the capture.

Figure 1 shows an example waveform for a 1-MHz transducer at a 3.6-MHz sampling frequency.

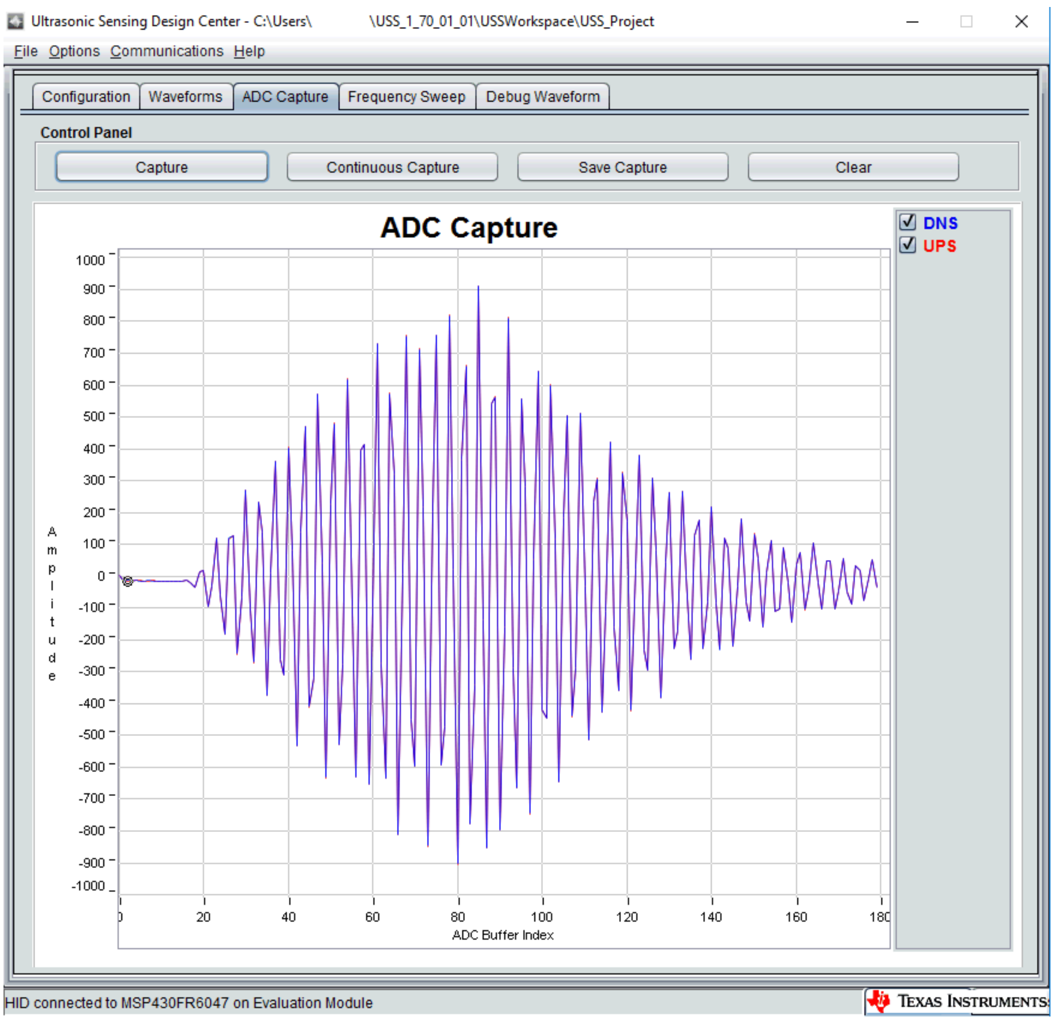


Figure 1. Typical ADC Capture

1.2 System-Level Performance Aspects Like Measurement Accuracy, Zero Flow Drift (ZFD), Impedance Matching

1. The MSP430FR604x device data sheets indicate that the USS flow meter has the highest accuracy for dTOF (differential time-of-flight) measurements (<25 ps for water and <500 ps (±250 ps) for gas). How are the values of 25 ps for water and 500 ps for gas derived?

   These values are based on tests done with customer pipes and transducers. The pipes are put in temperature ovens under zero-flow conditions, undergo temperature tests in the range of +5°C to +85°C for water or –35°C to +65°C for gas, and the test measures the differential time-of-flight (dTOF). The temperature variation is over approximately a 2-hour period for water. The average dTOF is taken over hundreds of measurements, and the drift (difference between the maximum and minimum measurements) in the dTOF value is evaluated over that temperature range. The values for dTOF are the results of this test. The MSP430FR604x MCUs have good impedance matching, but the final dTOF drift at zero flow also depends on how well the transducers are matched. More details about the specifics of the tests and results can be found in section titled "Test Results" in Ultrasonic Sensing Subsystem Reference Design for Water Flow Measurement for water flow meter applications and in Ultrasonic Sensing Subsystem Reference Design for Gas Flow Measurement for gas meter applications

   Figure 2 shows the variation in the dTOF over time and temperature for a water flow meter using a pair of 1-MHz transducers.

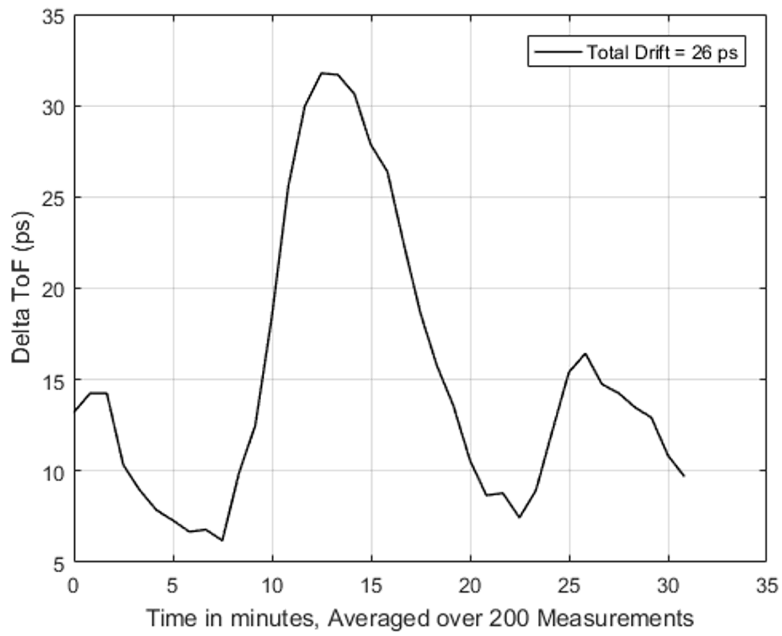


Figure 2. Zero Flow Drift (ZFD) of dTOF for Water Flow With Meter In Oven

Figure 3 shows the variation in dTOF over time and temperature for a gas meter.

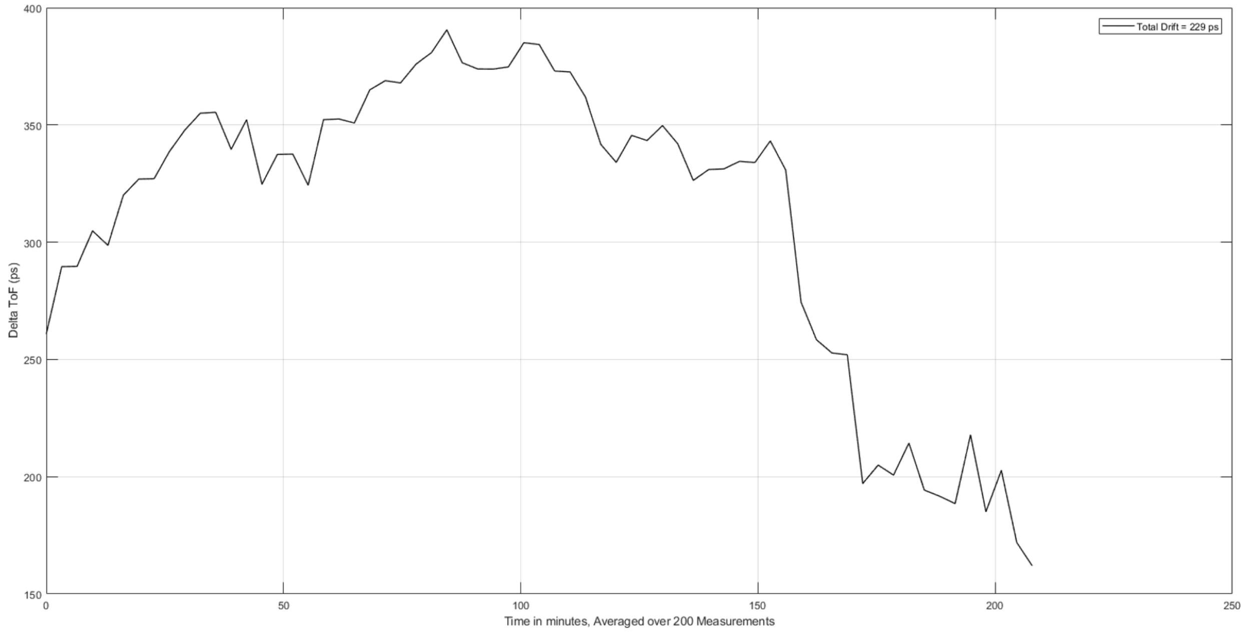


Figure 3. Zero Flow Drift (ZFD) for a Gas Meter Application

2. What averaging is used for the drift data and what is the measurement rate?

   The averaging was done over 200 measurements over 200 seconds. The measurement rate was 1 measurement per second.

3. The 25-ps accuracy for a water meter is based on testing. What is the theory for the estimation of this value?

   It is difficult to derive the exact number based on the theory, as it depends on the impedance matching of the electronics as well as the mismatches of the transducer impedances. The theory discusses the relationship and interdependencies of the different impedances, electronics and transducers.

4. There is big difference in accuracy between water meter and gas meter (25 ps for water and 500 ps for gas). What is the explanation for that?

   The drift in gas is higher, because of the difference in the properties of the medium. Gas is more diffusive when compared to water. The velocity of sound is also about 5x lower in gas compared to water, which leads to larger variations and drift in gas compared to water.

5. In practical applications, it is unacceptable to spend 100 or 200 seconds for one averaged data point of dTOF, because this delays the reporting to the meter. What is the resolution for this issue?

   This depends on the application. The instantaneous value of dTOF is available every measurement and can be used immediately. An application does not have to do any averaging to use this value.

   The application scenarios can be different.

   In applications in which the flow rate does not change rapidly and meter manufacturers are looking to smooth the measured values, the application can average over a number of measurements. The number is chosen based on the expected flow rate changes.

   In applications with faster flow rate changes, the application can increase the measurement rate. The MSP430FR604x MCUs can support a much higher measurement rate for both water flow meter and gas meter applications.

6. What determines the 5-ps resolution value? Are there any theoretical details for this value?

   The resolution depends on the signal-to-noise ratio (SNR) of the system, precision or number of bits of the ADC, and the accuracy and precision of the interpolation algorithm used in computing the dTOF from the correlation terms. TI obtained this resolution value based on system-level simulations that incorporated these parameters.

7. Good impedance matching reduces dTOF drift at zero flow. How can transducers be well matched? What parameters are most important? How can the matching be adjusted?

   The overall dTOF drift at zero flow depends on the impedance matching of the electronics that interface with the transducers, because of the reciprocity theory. The impedance of the transducers over temperature range of operation should be matched to each other (transducer 1 and transducer 2). The matching between the transducers affects the drift to some extent. The system does not require any precise matching of the impedance of the transducer with that of the electronics as long as they are within a reasonable range.

   - Water: For the transducers that have been tested, the 200-Ω termination resistor and capacitance on the EVM430-FR6047 has been used to obtain the performance results presented in Ultrasonic Sensing Subsystem Reference Design for Water Flow Measurement.
   - Gas: The external AFE on EVM430-FR6043 was designed for optimal impedance matching and has been used to test with a variety of transducers and results presented in Ultrasonic Sensing Subsystem Reference Design for Gas Flow Measurement.

8. What kind of signal processing is performed on the data output from USS_runAlgorithm function? What kind of signal processing is performed before the data are displayed in GUI?

   After receiving the dTOF, AbsTOF, and VolumeFlowRate (VFR) results from the USS_runAlgorithm or USS_runAlgorithmsFixedPoint function, the application only converts the internal fixed-point representation to a floating point number before sending the result to the GUI. The GUI displays the results from each measurement. No additional signal processing is done. Averaging is also done in the GUI for display purposes. The plot shows both the raw results from the USS_runAlgorithm function and the average.

   The number of samples used in the averaging in the GUI can also controlled by the user. The user can access the "Waveform Options" control panel by right clicking on the graph and choosing "Graph Options". More information can be found in the "Statistics" and "Waveform Options" section of the Ultrasonic Sensing Solution Design Center User Guide.

9. dTOF and volume flow rate data are noisy in the design center, even at zero flow. How can this be mitigated?

   - The GUI adjusts the zoom automatically depending on the input. If the dTOF is not varying much, the signal looks noisy even though the change is minimal. Try changing the flow rate to observe a more noticeable change.
   - A USB cable with ferrite can help reduce noise when connected to PC.
   - A clean power supply can help reduce noise.
   - Zero-flow-drift (ZFD) tests typically require the meter to be sealed to reduce water or air flow to the minimum possible.
     – Gas: Gas meters are usually placed inside a shielded case to reduce noise. In such case, connect the GND shield to the EVM430-FR6043 GND.
     – Water: Make sure the meter is filled with water and no bubbles are present.

10. What is the fastest measurement rate that the MSP430FR6047 or MSP430FR6043 can update the flow rate?

    The USS software library is designed for slow measurement rates of <10 Hz. In an experiment that modified some of the parameters in the .h files, measurement rates close to 500 Hz were obtained for a water flow meter application.

    The fastest data processing rate depends on the spacing between the transducers, the receive capture duration, and the spacing between the upstream (UPS) and downstream (DNS) firings. A test was done for water flow meter application with 1-MHz transducers inside a Jiakang pipe with spacing between the transducers of 73 µs, receive capture duration of 40 µs, and a UPS-to-DNS gap of 150 µs. This test gave a total measurement time of approximately 2 ms with MCLK = 8 MHz. The standard software is not designed for this type of application, so additional optimizations are possible:

    - The computation of previous measurement can be done while the next measurement firing and capture is in progress. Current software implements this in a serial blocking fashion.
    - MCLK can be set to 16 MHz, which should reduce computation time. Current software uses MCLK at 8 MHz.

    The fastest data processing rate is different for water flow meter and gas meter applications, because of inherent differences in the transducer excitation frequencies, differences in the number of pulses required for the two applications, differences in the gap between upstream and downstream firing, differences in capture durations, and differences in the processing times.

11. Is there an equation or a systematic way to do the calibration and determine a "Meter Constant" value?

    The general procedure is to use a reference meter to calibrate the meter constant to match the flow rate measured over the range of flow rates that need to be supported by the product:

    a. Use a nominal meter constant and run a series of flow tests at different flow rates across the entire range of flow rates that need to be supported. Use the reference meter to get the flow rate values and log both the flow rates from the reference meter and the measured volume flow rate from the MSP430FR604x Design Center GUI.
    b. In general, if the TI Design Center GUI shows X flow rate measured with meter constant M1, while the expected value is Y, the new meter constant M2 = M1 × (Y / X). For measurements at multiple flow rates, Yi and Xi, calculate a linear fit between {Yi} and {Xi} to obtain M2.

    Depending on the Maximum_Flow_rate_supported and Minimum_Flow_rate_supported, multiple meter constants might be required over the entire range. The necessary number of meter constants to use across the entire range depends on the final accuracy requirements. For example, if the product requires 1% accuracy, four meter constants may be needed over the entire range. With a relaxed 3% accuracy requirements, two meter constants might be sufficient.

12. Is the ultrasonic flow rate measurement going to change if the water temperature changes during testing?

    The volume flow rate (VFR) computation incorporates the variations in sound velocity due to fluctuations in water temperature. The absolute time-of-flight measurement (AbsToF) varies inversely with the speed of sound. You can find more information in the webinar High precision and accurate sensing at lowest flow rate for metering applications. This webinar includes an explanation for the derivation that eliminates the dependency on the speed of sound "c" and the temperature. Equation 1 shows the relevant equations from the webinar. The second line in the equation depends on AbsToF (T_{12}, T_{21}) but not on "c". Therefore, the measured volume flow rate is independent of temperature.

    Formula for average flow velocity:

    $$v = \frac{L}{2\cos\phi}\left(\frac{1}{T_{12}} - \frac{1}{T_{21}}\right)$$

    $$v = \frac{L}{2\cos\phi}\left(\frac{T_{21} - T_{12}}{T_{21}T_{12}}\right)$$

    $$v \propto T_{21} - T_{12} \rightarrow \Delta T$$

    Calculating the Volume:

    $$Q = \frac{\pi D^2}{4}\frac{L}{2\cos\phi}\left(\frac{\Delta T}{T_{21}T_{12}}\right) = \underbrace{\frac{\pi D^3}{4\sin(2\phi)}}_{\text{Area}}\underbrace{\left(\frac{\Delta T}{T_{21}T_{12}}\right)}_{\text{Flow velocity}} \qquad (1)$$

13. Can the MSP430FR6047 and MSP430FR6043 MCUs support flow rates as high as 40 gpm (8800 lph) for water flow meters?
    What is the maximum flow rate supported by the MSP430FR6047 and MSP430FR6043 MCUs?

    MSP430FR6047 and Ultrasonic Software Based Water Flow Meter Measurement Results demonstrates that the MSP430FR6047 MCU with the USS software library and the example application code can support 40 gpm (8800 lph). The results obtained with MSP430FR6047 MCU are also applicable to the MSP430FR6043 MCU as the underlying USS module is the same as far as water flow meter application is concerned. Customers have also tested flow rates >130 gpm in a DN45 pipe, which is equivalent to 40 gpm in a DN25 pipe. The maximum supported flow rate depends on the pipe size. The existing software supports flow rates with DToF of multiple transducer cycles. For example, 3 transducer cycles is equivalent to support a flow rate which equals a DToF of 3000 ns with 1-MHz transducers.

14. What transducers work with the MSP430FR604x solutions?

    The transducers from the following manufacturers should work with the MSP430FR604x based ultrasonic solutions. The water flow meters have been tested using 1-MHz and 2-MHz transducers. The gas meters have been tested using transducers ranging from 200 kHz to 500 kHz.

    - Audiowell: Brass pipe for heat meter model number HS0003-001 and Ultrasonic flow sensor model number T/R975-US0014L353-01
    - Jiakang: Ultrasonic flow sensor model number PSC1.0M020100H2ADX-B0
    - Hurricane: 1-MHz ultrasonic flow meter sensor model number TL1000 (water) and ultrasonic transducer for gas flow meter – TG020012 (gas)
    - CeramTec: Ultrasonic flow sensors for utilities management. These include 1-MHz and 2-MHz transducers for water (or other liquids) and 200-kHz and 400-kHz transducers for gas.

    For typical water flow rates, 1-MHz and 2-MHz transducers should work with this solution and should give good performance without regard to the specific transducer model.

    Similarly, for typical gas flow meter applications, the 200 kHz and 400 kHz transducers in the list above should give good performance. The USS IP block in the MSP430FR604x devices supports transducer frequencies from 133 kHz to 2.5 MHz.

15. How much variation is observed in dTOF across different MSP430FR604x MCUs or transducer pairs?

    For water flow meters, variations in dTOF across different MCUs or across different transducer pairs have been seen in the order of tens of picoseconds. These observations were made with the EVM430-FR6047 with no additional external components in the path between the transducers and the MSP430FR6047 MCU.

    Measurements have also been made using the Ultrasonic Sensing Water Meter Front-End Reference Design, which supports two pairs of transducers and uses external multiplexers and gain amplifiers. Using this board, DToF variations in the range of hundreds of picoseconds have been seen. This range is entirely due to the variation in the path between the different multiplexers or amplifiers.

16. Can the received ADC capture signal be filtered before computation of delta time-of-flight (DToF), absolute time-of-flight (AbsToF), and Volume Flow Rate (VFR)?

    In some scenarios, dependent on the transducer characteristics, the received signal at the ADC output might need to be filtered to remove interferers. Filtering can be done by enabling the configuration parameter USS_Algorithms_User_Configuration::enableFilter. The filter coefficients are specified by USS_SW_LIB_APP_FILTER_COEFFICIENTS in USS_userConfig.h, which are populated in USS_Algorithms_User_Configuration::filterCoeffs in USS_userConfig.c. The default filter is designed for a transducer frequency of 1 MHz with a 400-kHz bandwidth, and coefficients are generated using the firpm function in Matlab. The following matlab code is for a sampling frequency of 3.6 Msps:

    ```
    N = 18; fs = 3600000; Fstop1 = 600000; Fpass1 = 800000; Fpass2 = 1200000;   Fstop2 = 1400000;
    Wstop1 = 1;  Wpass = 10;  Wstop2 = 1;
    filterCoeffs = [firpm(N,[0 Fstop1 Fpass1 Fpass2 Fstop2 Fs/2]/(Fs/2), [0 0 1 1 0 0],[Wstop1
    Wpass Wstop2]) 0];
    ```

    The "filterCoeffs" variable above needs to be converted to fixed-point representation before being used in USS_userConfig.h. The filter size and filter characteristics can be modified by changing the application software code.

17. Is there a configuration setting to enable measurement of high flows? Is there a change to the current consumption with this option?

    The default setting for USS_ALG_DTOF_COMPUTATION_MODE in USS_userConfig.h is USS_ALG_DTOF_COMPUTATION_OPTION_ESTIMATE. This supports a very high range of flow rates. This setting allows for flow rates up to a delta time-of-flight (DToF) of multiple transducer cycles. As an example, for a transducer frequency of 1 MHz, 3 transducer cycles is equivalent to3 µs. A DToF of 1.5 µs equals a flow rate of approximately 40 gpm (or 8800 lph) on a DN25 pipe.

    The current consumption with this setting for USS_ALG_DTOF_COMPUTATION_MODE is generally similar across a wide range of flow rates. The current measurements presented in the reference design document Ultrasonic Sensing Subsystem Reference Design for Water Flow Measurement are performed at zero flow.

18. What is the smallest flow rate at which an accuracy of 1% is achievable?

    This generally depends on the accuracy class of water flow meters. The EN ISO 4064-1:2014:11 standard defines the class 1 meters to have an accuracy requirement of 1% for temperatures 0.1°C to 30°C in a given flow rate zone. Below this flow rate zone, they have a more relaxed accuracy requirement of 3%. As an example, the flow rate zone of 1% accuracy requirement can be between a flow rate zone of 0.03 to 15 gpm (6.6 lph to 3300 lph). This particular example has a ratio of 500 between the highest and lowest flow rate in that specified flow rate zone.

    Obviously, the actual values of the flow rate zones depend on the dimensions of the pipe. The above are just examples of some aspects of the standard on the accuracy requirements.

1.3 Software Features and Possible Modifications to Support Additional Features or Capabilities

1. How can my software get the maximum amplitude of the received ADC waveforms?

   In the function USS_startUltrasonicMeasurement() or USS_startLowPowerUltrasonicCapture() in USSLibGUIApp.c, add a function to search for the maximum and minimum of the captured downstream and upstream signals. The captured waveforms are stored at gUssSWConfig.captureConfig.pCapturesBuffer. The memory buffer has the structure sampleSize × numberOfAcquisitions × 2, as in the documentation for the USS software Library. numberOfAcquisitions is usually 2 or 1 for upstream and 1 for downstream.

   This added function can send the maximum and minimum values to the GUI using the debug panel or can reuse the values in the application.

   If this functionality is required as part of the application in the field, and if cycle count needs to be optimized, you can also use LEA to implement this functionality. For more information on the LEA and adding code to implement the functions to run on LEA, refer to the MSP430FR6047 Ultrasonic Sensing Design Center User's Guide and Benchmarking the Signal Processing Capabilities of the Low-Energy Accelerator.

2. Does the ultrasonic software library support measurement using external triggers without the use of software triggers?

   In ultrasonic software library version 02.10.00.07 or 02.20.00.xx, the measurement is only started by software using USS_startUltrasonicMeasurement() or USS_startLowPowerUltrasonicCapture().

   The USS module in the MSP430FR6047 or MSP430FR6043 MCUs supports a hardware trigger from the TA1 CCR2 output that can be used to start the measurement. To use the hardware trigger, the CPU must be in LPM0 or active mode to make sure that the USS module is powered on. See the ASQ trigger signal connections table in the MSP430FR604x(1), MSP430FR603x(1) Ultrasonic Sensing MSP430™ Microcontrollers for Water-Metering Applications data sheet for more information. Also see the ASQ block diagram in the MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide.

   The library software must be modified to support this hardware trigger. This enhancement can be done using the source code already provided as a starting point.

3. Do the interrupts need to be disabled during the ultrasonic measurement or dTOF computations? If yes, what is the duration or cycles when they are disabled?

   The interrupts are only disabled in the function `void commonWaitForconversion(USS_capture_power_mode_option mode)` in the file ussSWLib/source/common/ussSwLibCommonUSS.c. The interrupts are enabled before returning from the function. Based on benchmark tests, the interrupts are disabled for approximately 66 MCLK cycles, which corresponds to approximately 8.25 µs with MCLK = 8 MHz and approximately 4.125 µs with MCLK = 16 MHz.

1.4 LCD Display, Ultrasonic Sensing Design Center GUI Display and Configuration

1. I would like to know about the Meter Constant parameter in the configuration panel. How can I calculate that? Is there any document that I can refer?

   The meter constant parameter is used to calibrate the meter to a desired flow rate. For example, assume that the meter must measure a flow rate in the range of 1 gallon per minute.

   a. Set up a reference meter in series with the designed meter.
   b. Use the reference meter to validate a 1-gpm flow rate.
   c. In the Ultrasonic Sensing Design Center GUI, look at the Volume Flow Rate window in the Waveforms tab to see what flow rate the designed meter is recording.
   d. Adjust the Meter Constant value until a 1-gpm flow rate is measured by the designed meter.

   TI plans to release an update to the GUI to automate this process. Until this update is available, using a manual method like the one above is the recommended method to find the proper meter constant value.

2. What is the maximum value that can be applied to the meter constant? Is it 19999999.00? I tested my application using the system at a constant flow rate of 20 lph. With the meter constant set to 19999999.00, I observed only 7.5 lph in the LCD and in GUI. Is there any other parameter I need to adjust? Or do I need to calibrate it with a much higher flow rate?

   The maximum value that can be applied to the meter constant value is 22742000, because of the fixed point implementation in the software library. For more information, refer to the MSP430FR6047 Ultrasonic Sensing Design Center User's Guide.

   There are two ways to correct detected flow rate of the meter.

   - Change the units to gallons per minute. You should see approximately 0.088 gpm.
   - To keep the measurements in lph, you must change the application code and apply a scale factor of 10x to the volume flow rate.

   Setting the meter constant to (20 / 7.5) × 19999999 would correct the calibration, but this value is greater than the maximum value of 22742000. A scale factor of 10x on the volume flow rate allows the meter constant to be (20 / 75) × 19999999, which is within the acceptable meter constant range. In the hmi.c file, multiply the volume flow rate by 10. In the HMI_PostAlgorithm_Update routine, use

   ```
   DC_User_Params->plot_vol_flow_rate = (float) 10.0*(alg_results_float.volumeFlowRate);
   ```

   instead of

   ```
   DC_User_Params->plot_vol_flow_rate = alg_results_float.volumeFlowRate;
   ```

3. What is a good setting for the PGA?

   Set the PGA value so the maximum of the ADC waveform is approximately 1000 codes for transducer frequencies between 200 kHz to 1 MHz. This corresponds to a backoff of 6.25 dB.

   If the automatic gain control (AGC) calibration API is enabled using `#define USS_APP_AGC_CALIBRATE` in USS_App_userConfig.h, this can also be accomplished by setting `#define USS_AGC_CONSTANT 60` in USS_userConfig.h. This applies to both water flow meters that use 1-MHz transducers and to gas meters that use transducers with excitation frequencies between 200 kHz and 500 kHz.

   The values for 2-MHz transducers are 650 codes for the maximum of the ADC waveform, which corresponds to a backoff of approximately 10 dB. If AGC is enabled, this can be accomplished by setting USS_AGC_CONSTANT = 56.

4. What configuration settings need to be modified specifically for 2-MHz transducers?

   For 2-MHz transducers, the PGA should be set such that the maximum of the ADC waveform is approximately 650 codes. If AGC is enabled, this can be accomplished by setting USS_AGC_CONSTANT = 56. Additionally, in USS_userConfig.h, set `#define USS_ALG_RATIO_OF_TRACK_LOBE 0.2`. This value is used in Algorithms_API for absolute time-of-flight (AbsToF) computation.

5. Why use different values of USS_AGC_CONSTANT for 1-MHz and 2-MHz transducers? Does changing this value limit the range by which the AGC can vary the gain from 60 db to 54 db in the case of 2-MHz transducer? Are there any limitations while using the 200-kHz to 500-kHz transducer frequencies with gas meter applications?

   The reason for setting USS_AGC_CONSTANT = 54 for 2-MHz transducers is because the internal PGA on the chip and SDHS supports a lower signal level for 2-MHz signals compared to 1-MHz signals before the signal starts to distort. This lower setting for 2 MHz results in having approximately 600 to 700 ADC codes at the ADC output, which limits the available ADC range by 1 bit for 2-MHz transducers.

   For gas meters that use transducer frequencies of 200 kHz to 500 kHz, USS_AGC_CONSTANT can be the same as the frequency response of the on-chip SDHS is similar across these lower frequencies. More information can be found on the frequency responses of the SDHS module in Section 22.2.3, *Digital Output*, of the MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide.

6. Can the RX bias be applied during transmit, or should it be applied after transmit, before sampling of the input signal? This is in reference to the *Six Time Mark Events* section in the MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide.

   The RX bias can also be applied at the same time as application of TX bias.

   In water meter applications, the sample code from TI uses TMC = 0 for all silicon revision B MSP430FR6047 MCUs, which ensures that both TX and RX biases are applied at the same time.

   In gas meter applications, the default configuration from TI applies the RX bias 200 µs after the TX bias is applied and while the TX excitation pulses are being applied.

7. What are the considerations while using the meter calibration functionality in the water meter project or the Calibration panel in the Ultrasonic Sensing Design Center GUI?

   For the meter calibration functionality, in the Ultrasonic Sensing Design Center GUI, the "Volume Flow Rate Calibration Ranges" configuration parameter on the Parameters panel, the "Adv Calibration Table" button on the Waveforms panel, and the Calibration panel are all interdependent.

   Follow the directions in the "Calibration" section of the USS Design Center User’s Guide to calibrate your meter for multiple ranges. After the Calibration panel in the GUI has been populated with the correct slopes and offsets for each range, perform the following steps:

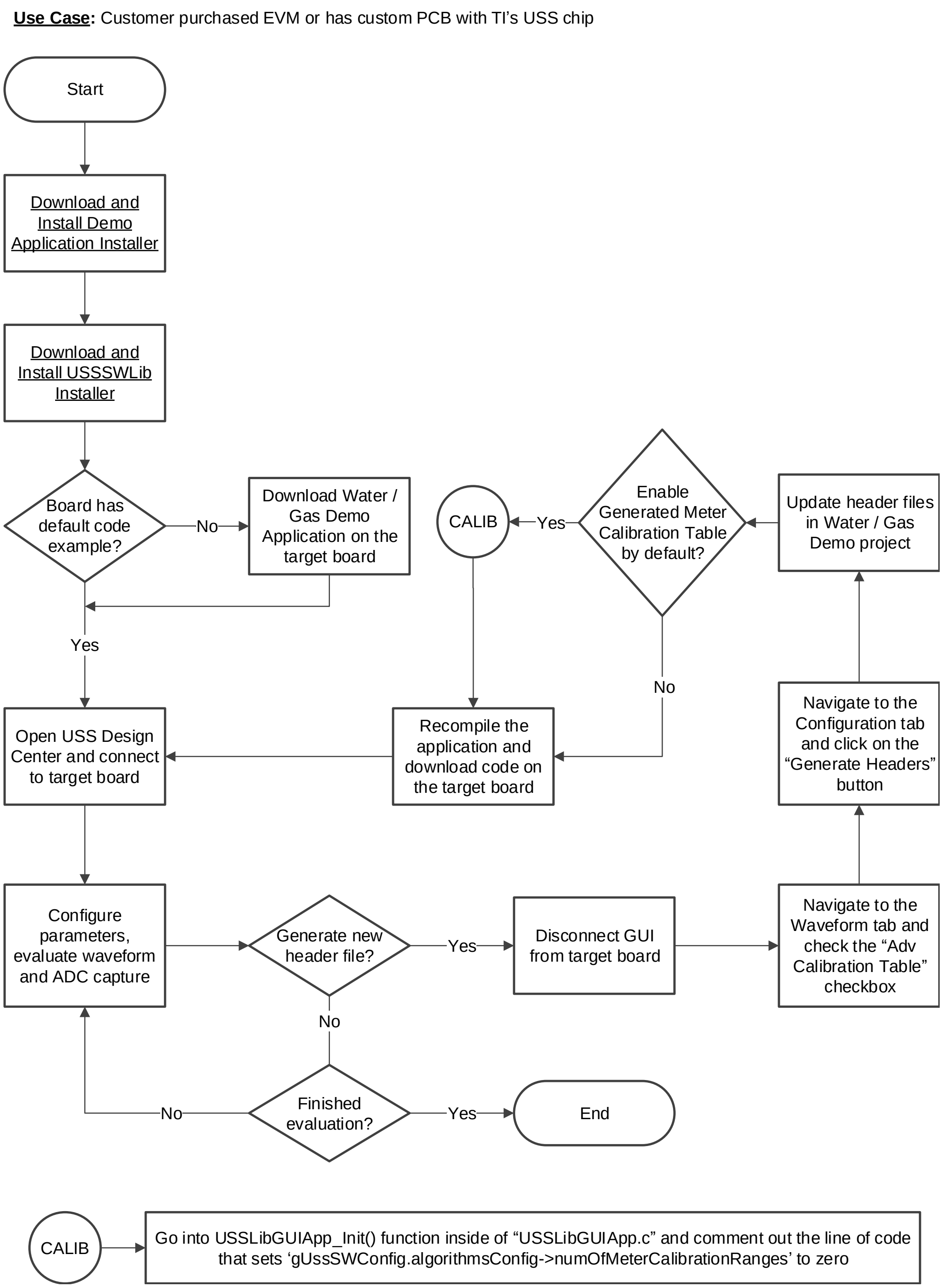
   a. Disconnect the meter from the GUI.
   b. Navigate to the Waveforms tab and click the "Adv Calibration Table" button.
   c. Generate headers and program the device with the updated header files.

   NOTE: The use of the meter calibration table for multiple ranges is disabled in the water meter demo application by default, allowing the user to activate it in the GUI waveforms tab.

   To enable use of the generated meter calibration table by default, without connecting to the GUI, the application user must edit the *USSLibGUIApp_Init()* function in USSLibGUIApp.c and comment out the line of code that sets *gUssSWConfig.algorithmsConfig->numOfMeterCalibrationRanges* to zero.

8. How can the user adjust the number of samples used for computing the statistics in the Ultrasonic Sensing Design Center GUI?

   The user can access the Waveform Options control panel by right clicking on the graph and choosing Graph Options. More information can be found in the "Statistics" and "Waveform Options" section of the Ultrasonic Sensing Solution Design Center User Guide. The flowchart in Figure 4 should help improve the expected usage.



NOTE: The use of the meter calibration table for multiple ranges is disabled in the water meter demo application by default, allowing the user to activate it in the GUI waveforms tab.

Figure 4. Meter Calibration Flow Chart

2 References

1. MSP430 MCUs Ultrasonic Design Center
2. MSP430FR6047 Ultrasonic Sensing Evaluation Module
3. EVM430-FR6047 Hardware Guide
4. Ultrasonic Sensing Subsystem Reference Design for Water Flow Measurement
5. MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide
6. MSP430FR6043 Ultrasonic Sensing Evaluation Module
7. EVM430-FR6043 Hardware Guide
8. Ultrasonic Sensing Subsystem Reference Design for Gas Flow Measurement

Revision History

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

Changes from May 14, 2018 to January 30, 2019 **Page**

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