Application Note

Ultrasonic Sensing Solution (USS) Guide

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ABSTRACT

This application note points out common problems encountered by customers when using the USS Driver Library to implement ultrasonic water and gas meter applications based on MSP430FR604x, MSP430FR600x, MSP430FR504x MCU.

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Trademarks

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1 Introduction

The following are the topics described in this application note:

- Measurement theory introduction
- Implementation on MSP430 MCU
- Hardware design for water meter and gas meter
- USS library and demo project

2 Flow Meter Measurement Theory

The ultrasonic flow meter design is based on the principle of ToF measurement. This measurement refers to the time a signal takes to travel from a transmitting transducer to a receiving transducer. Figure 2-1 shows a typical flow pipe.

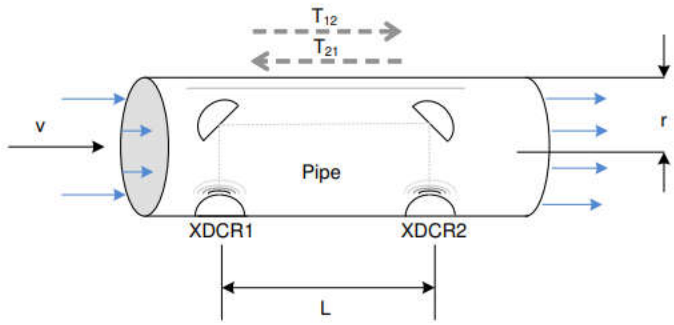

Figure 2-1. Typical Flow Pipe

The propagation time of a signal traveling from the first transducer to the second transducer is given by T12. T21 represents the propagation time in the opposite direction. Calculate these timings according to the following equations as a function of the velocity of the ultrasound in gas and the velocity of gas flow. Because this length is much larger than the radius of the pipe, r, the propagation length of the wave that is perpendicular to the flow is considered to be negligible in the following analysis.

$$T_{12} = \frac{L}{c + v} \tag{1}$$

$$T_{21} = \frac{L}{c - v} \tag{2}$$

$$\Delta t = T_{21} - T_{12} \tag{3}$$

where:

- c is the velocity of the ultrasound in the medium.
- v is the velocity of gas flow.
- L is the propagation length of the pipe along the flow of gas.

Use Equation 1 through Equation 3 to derive the velocity of gas flow (v), which is possible even without knowing the velocity of the ultrasound in the medium (c). This reference design calculates gas flow assuming that the velocity of the ultrasound is unknown. In this case, derive Equation 4 from Equation 1 and Equation 2 by eliminating c.

$$v = \frac{L}{2} \times \left(\frac{1}{T_{12}} - \frac{1}{T_{21}}\right) = \frac{L}{2} \times \left(\frac{T_{21} - T_{12}}{T_{21} \times T_{12}}\right) = \frac{L}{2} \times \left(\frac{\Delta t}{T_{21} \times T_{12}}\right) \tag{4}$$

2.1 TOF Measurement Algorithm Implementation

The ADC-based approach to estimate the absTOF is Lobe for water meter application and Hilbert Wide for gas meter application, while the differential ToF for both water and gas meter are based on cross-correlation techniques.

Table 2-1. Measurement Algorithm for Water Meter and Gas Meter

Algorithm	Water Meter	Gas Meter
absTOF	Lobe	Hilbert Wide
dTOF	Cross-Correlation	Cross-Correlation

2.1.1 AbsTOF Calculation Method – Lobe

Estimating an accurate absToF in water means that a temperature sensor is not needed to compute the velocity of sound in water. In the USS SW Library used in this reference design, the absToF is determined by computing the envelope of the received signal.

A peak value for each lobe is first computed. Then, the maximum lobe peak is chosen. The envelope crossing threshold as a given ratio of this maximum is then determined. The algorithm picks the nearest lobe peak to the threshold as the absTOF measurement end point. The absToF is then calculated by a constant offset from this threshold crossing of the envelope, as shown in below figure.

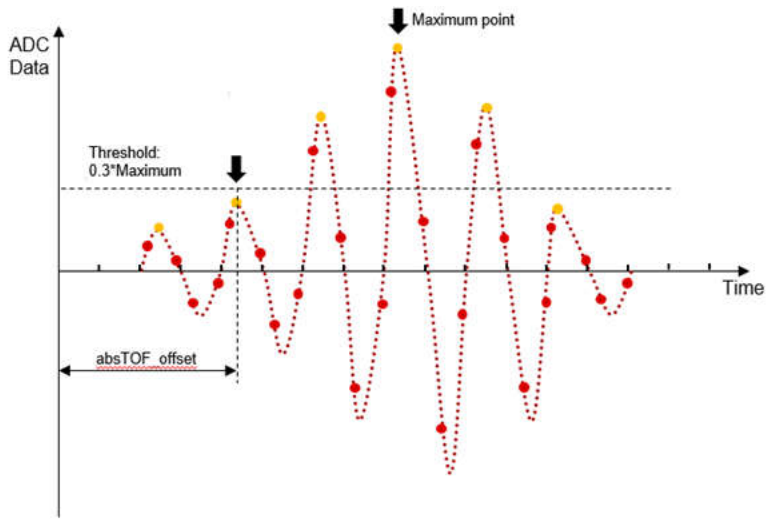

Figure 2-2. Lobe Algorithm

The UPS and DNS absToF are therefore given by Equation 5.

$$absTOF = T_{prop} + T_{absTOF\_offset} \tag{5}$$

where:

- Tprop is the propagation time which is preprogrammed from USS Design Center GUI (gap between pulse start and ADC capture) or application configuration and corresponds to approximate propagation time for the ultrasound signal in the given meter.

Typically, this value can range from 35 to 70μs. The absTOF offset corresponds to the time from the ADC trigger to the envelope crossing a certain ratio of the signal maximum. TI recommends to choose the second visible lobe according to the ADC capture data, since the first lobe is usually weak and sometimes hard to distinguish from the noise.

2.1.2 AbsTOF Calculation Method – Hilbert Wide

Estimating an accurate absToF in gas means that a temperature sensor is not needed to compute the velocity of sound in gas. In the USS SW Library used in this reference design, the absToF is determined by computing the envelope of the received signal through Hilbert transform. A maximum of the envelope for each capture is first computed. The envelope crossing as a given ratio of this maximum is then determined. The absToF offset is then calculated by the two envelope points crossing the threshold and the threshold line, as shown in Figure 2-3.

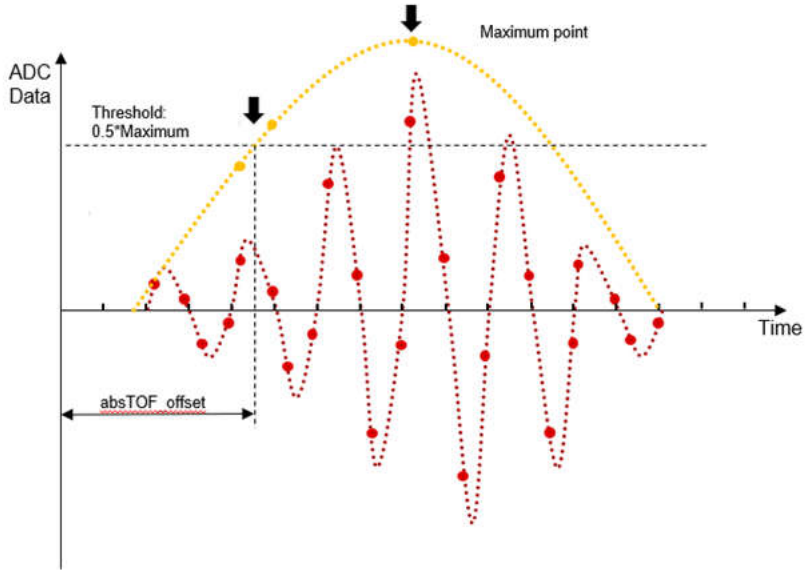

Figure 2-3. Hilbert Wide Algorithm

The UPS and DNS absToF are therefore given by Equation 6.

$$absTOF \quad = \quad T_{prop} + T_{absTOF\_offset} \tag{6}$$

where:

- Tprop is the propagation time which is preprogrammed from USS Design Center GUI (gap between pulse start and ADC capture) or application configuration and corresponds to approximate propagation time for the ultrasound signal in the given meter.

Typically, this value can range over 150us. The absTOF offset corresponds to the time from the ADC trigger to the envelope crossing a certain ratio (typically chosen to be 50%) of the envelope maximum.

2.1.3 dTOF Calculation Method - Cross-Correlation

Cross-correlation is a widely used technique in signal processing to measure the similarity and time-delay relationship between two signals. The core idea is to slide one signal (called the reference signal) against another signal (called the input signal) and compute the dot product to find the best match at different delays.

For discrete signals x[n] and y[n], the cross-correlation function Rxy[k] can be expressed as:

$$R_{xy}[k] \quad = \quad \sum_{n = -\infty}^{+\infty} x[n]y[n+k] \tag{7}$$

where, k is the time delay of signal y relative to signal x. The output result Rxy[k] provides information about the degree of similarity between the two signals at the delay k.

The output cross-correlation sequence Rxy[k] reveals the correlation at different delays, and usually, the delay value k that maximizes the cross-correlation is sought as the time delay between the two signals. So, the goal is to find the delay k value, which gets the largest Rxy[k] value. In the dTOF calculation, use the UPS and DNS receive signal as the two inputs of the cross-correlation algorithm. In this case, the delay k represents the time difference between the two receive signals which can be considered as the dTOF value. Figure 2-4 shows an example that demonstrates how to calculate the cross-correlation from two discrete signals (k = 0).

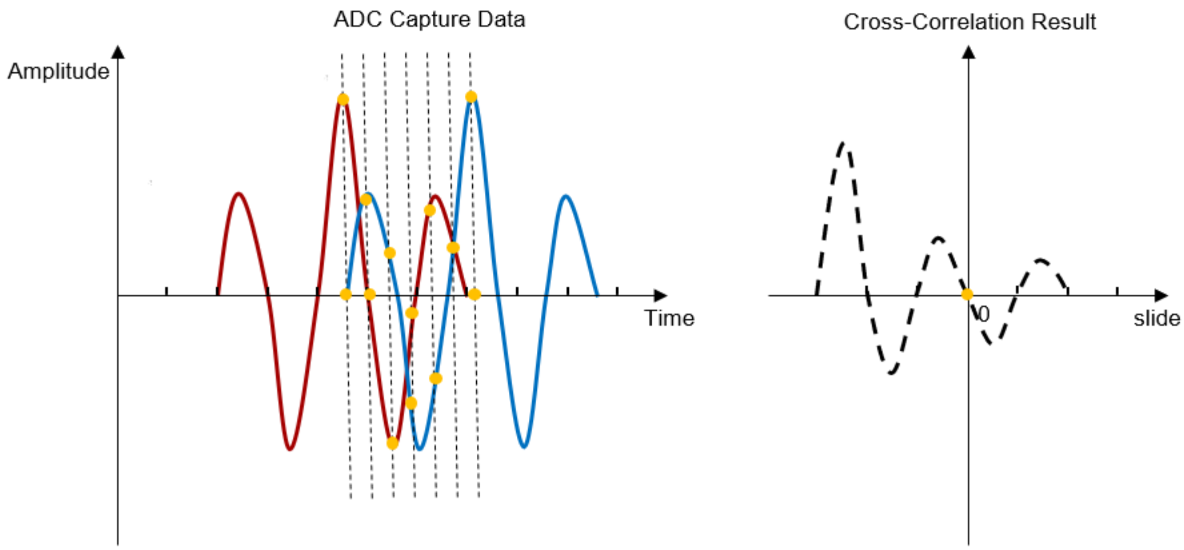

Figure 2-4. Cross-Correlation Calculation

Figure 2-5 shows an example demonstrates how to calculate the cross-correlation from two discrete signals with one cycle slide left on the blue signal (k = -1).

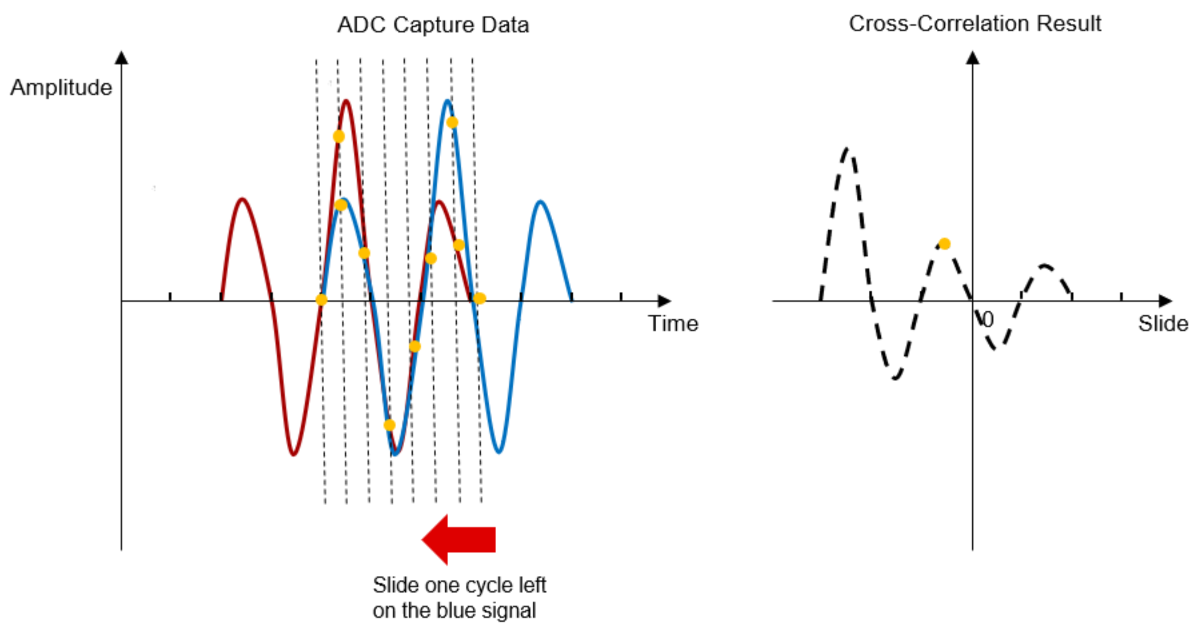

Figure 2-5. Cross-Correlation Calculation with One Cycle Slide Left on Blue Signal

Figure 2-6 shows an example demonstrates how to calculate the cross-correlation from two discrete signals with five cycle slide left on the blue signal (k = -5). Under this k = -5 value, since the two signals are overlapped, the maximum cross-correlation result is achieved.

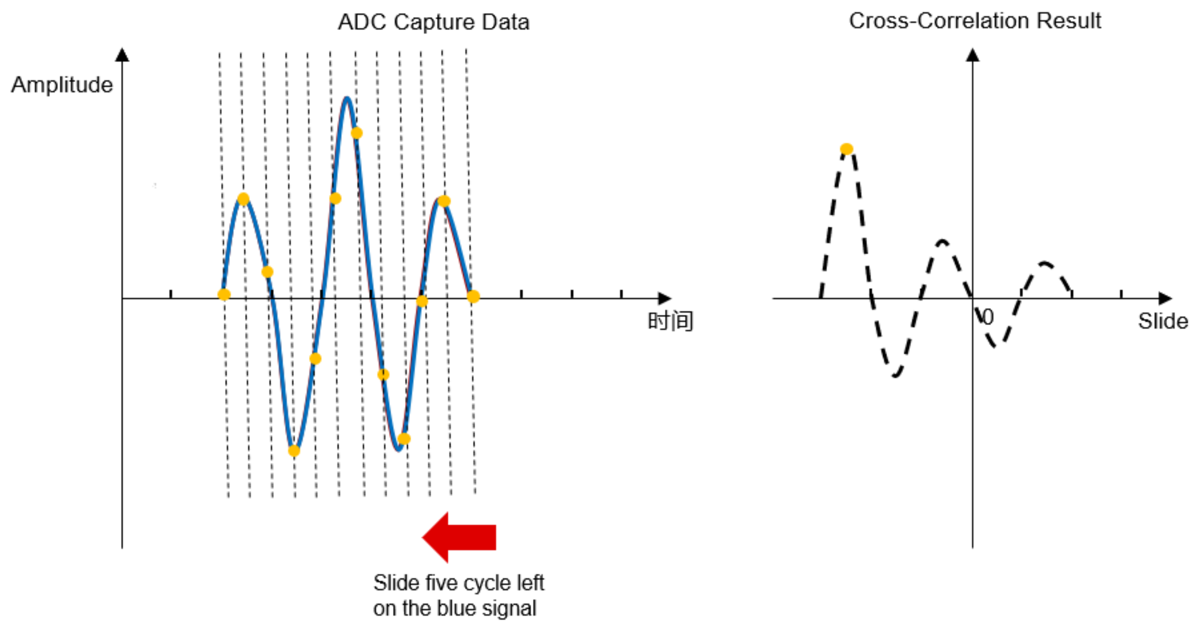

Figure 2-6. Cross-Correlation Calculation with Five Cycle Slide Left on Blue Signal

2.1.3.1 Get a High-Precision dTOF Result

Since the received signals are all discrete signals, the delay k is also chosen as integer. This cannot meet the accuracy requirement on the dTOF result. Use Figure 2-7 as an example.

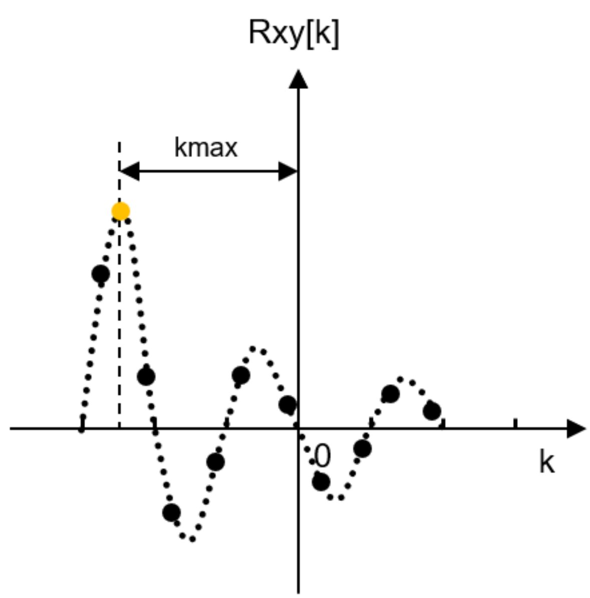

Figure 2-7. Cross-Correlation Interpolation

The black points are Rxy[k] values. Find the maximum point of the Rxy[k] value with the kmax value. In the USS library, use the cosine interpolation with the three nearest point to calculate the high-precision kmax value. There are more high performance interpolation algorithms that can be used here. However, considering the MCU ability and power consumption, choose the cosine interpolation in USS library to use. With this method, the USS library can reach up to 5ps for dTOF resolution.

2.1.3.2 Optimization in Cross-Correlation Method

In the USS library, minimize the calculation process to get a better current consumption performance. The dTOF calculation is divided into two parts:

1. Coarse calculation: Uses the calculation results of the absTOF UPS and DNS result. Calculate the integer part of the delays between them. Slide the DNS signal according to this result first and then run the cross-correlation process.
2. Fine calculation: run the cross-correlation process with the slide DNS signal.

The total dTOF result is calculated in Equation 8.

$$dTOF = (integer\ part\ from\ absTOF\ results) + (decimal\ part\ from\ cross\ correlation\ method) \quad (8)$$

Use Figure 2-8 as an example.

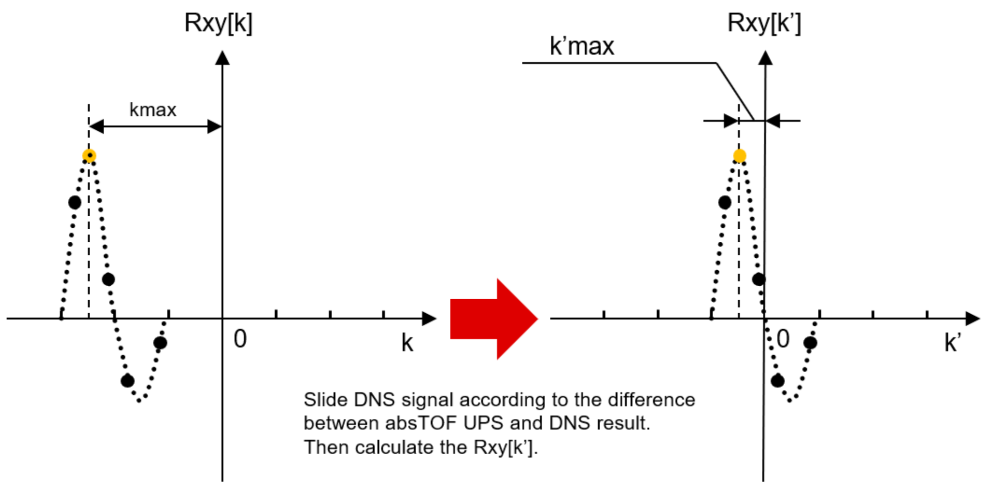

Figure 2-8. Cross-correlation optimization

The integer part of the dTOF result is given by the time difference from absTOF UPS and DNS results. The USS library does not need to slide the DNS signal for multiply times and calculate the cross-correlation result to find the maximum Rxy[k] result. Users need to know exactly how many cycles to slide the signal to get the maximum point of the Rxy[k] result based on the absTOF UPS and DNS results. This saves a lot of data processing time and current consumption.

2.2 Differences between ADC Approach and TDC Approach

The fundamental difference between those two approaches is about the signal processing.

- ADC approach (cross-correlation using the ADC captured signal): samples four times in each cycle of the signal. The correlation method gives the digital filtering to suppress the noise down.
- TDC approach (zero-crossing using a time-to-digital converter (TDC): samples two times in each cycle near the zero crossing point. Noise affects each zero crossing time with no digital filtering possible in TDC approach for noise suppression.

The ADC approach has a benefit of being approximately 3-4 times lower of the standard deviation data of the dTOF. The ADC is robust to signal amplitude variations. The algorithm is insensitive to the received signal amplitude as in high flow rates, transducer to transducer variation, temperature variation, different gas compositions (air, methane). And, since the envelope of signal is obtained naturally in ADC approach, users can implement more customize functions.

3 MSP430 MCUs for USS Application

3.1 USS Module

The **USS** module is designed for analog-to-digital (ADC) converters based on ultrasonic sensing technology in various measurement applications. Figure 3-1 shows the block diagram of USS module.

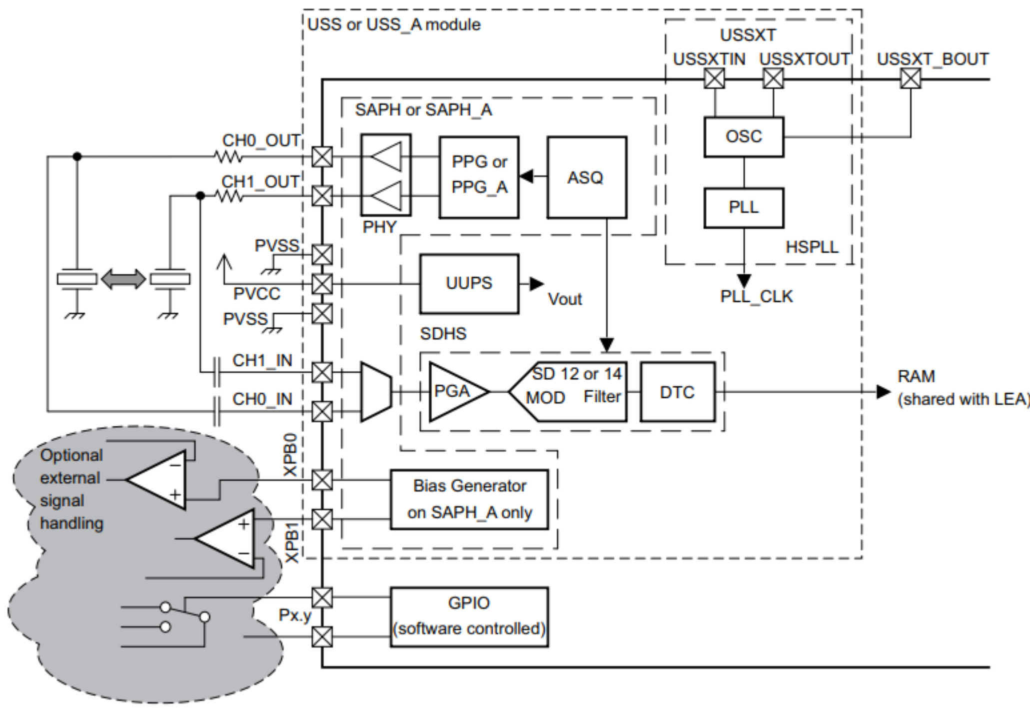

Figure 3-1. USS Block Diagram

The USS is a sophisticated system that consists of the following four submodules. USS_A is an extended variant of the original USS module and features SAPH_A instead of the SAPH module. Because USS_A is a superset of USS, USS_A is specifically named only when describing features that differ between USS and USS_A.

The main devices integrated with the USS module and the major differences between them are listed in Table 3-1. For more details, see also the device data sheet and user's guide.

Table 3-1. MSP430 MCUs with USS Module

MCU Devices	FRAM	LCD	USS Module	Application	Performance
MSP430FR6005	128 kB	Yes	USS	Water meter	Normal
MSP430FR6007	256 kB	Yes	USS	Water meter	Normal
MSP430FR6045	128 kB	Yes	USS	Water meter	High
MSP430FR6047	256 kB	Yes	USS	Water meter	High
MSP430FR5043	64 kB	No	USS_A	Water & Gas meter	High
MSP430FR6043	64 kB	Yes	USS_A	Water & Gas meter	High

3.2 Differences Between USS and USS_A Module

The SNR of the receive signal is much lower in gas meter than in water meter application. Noise is a problem that cannot be ignored especially in gas meter. Use different approaches to solve the noise issue on both the hardware and software side for gas meter application. The method for software was described earlier, and the differences in the hardware side are described below.

From the table, the USS_A module can be used in gas meter applications. The major difference between the USS and USS_A module is the Sequencer for Acquisition, Programmable Pulse Generator, and Physical Interface (SAPH module).

SAPH: Consists of an extended pulse generator, a low-impedance output driver, an input multiplexer, an acquisition sequencer and external bias terminals.

The SAPH_A module can generate multitone. The output pulses consist of multiple phases. The multitone feature is important for the absTOF calculation in gas meter applications. The binary pattern of the generated excitation signal is used to filter out noise on the UPS, DNS ADC capture signal before processing the Hilbert transform. This multitone feature lowers the impact of noise signal and makes the ADC approach successful when used in gas meter applications.

3.3 Software Implementation on MSP430 MCUs

MSP430FR60xx and MSP430FR50xx MCUs performs the complete acquisition process using integrated an USS module in the device for signal conditioning. Below figure shows this acquisition process.

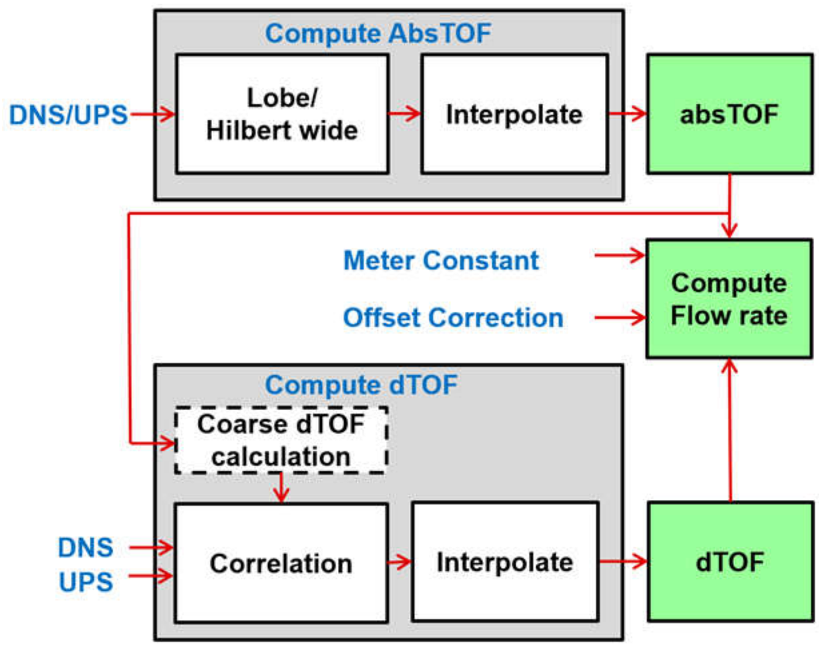

Figure 3-2. Calculation Process

At the beginning of the sequence, MCU sends a train of pulses to the first transducer. The signal is then received by the second transceiver, after propagation time T12. The difference in time between transmission and reception determines the upstream (UPS) TOF.

Then, MCU repeats the same process in the opposite direction during the downstream stage, resulting in the propagation time, T21, which represents the downstream (DNS) TOF.

The dTOF can be calculated as the difference between T12 and T21 using the correlation method. According to Section 2.1.3.2, the USS library uses the absTOF result for reference to give the integer cycle differences between the absTOF results. And uses the cross-correlation method to provide the decimal part of dTOF result. With this method, we get the dTOF result.

The flow rate result is calculated based on absTOF, dTOF, meter constant and offset correction value according to Section 2.

4 Hardware Design Flow

4.1 Schematics

4.1.1 Water Meter Schematic – MSP430FR6047 and MSP430FR6007

This is a highly integrated design using MSP USS MCUs for the water meter application. For more details, see the TIDM-1019.

There are only a few points which need to be highlighted.

1. For the USSXT, TI recommends to choose the load capacitor value by using Equation 9.

$$C_{crystal} + C_{load} + C_{layout} = 34pF \tag{9}$$

   Since the ADC approach is used in the USSLib, the measurement accuracy is barely affected by the crystal oscillator accuracy. Therefore, use a resonator on EVM boards for demonstration with good performance. A resonator also consumes less current than a crystal. If users do not care about the current consumption and have a wide temperature range in the application, then users can consider to use a crystal to replace the resonator. Users need to modify the USS_HSPLL_INPUT_CLK_TYPE and USS_HSPLL_USSXTAL_SETTLING_USEC in the software.
2. For the CHx_IN/OUT circuit, TI recommends to use 1% resistors and 1% NP0 capacitors for a better USS performance. Users can change the value of the resistor and capacitor if this helps to get a better performance on the meter. As a note, TI tested several combinations with different transducers and took the value with 200Ohm and 1000pF for the best performance.
3. For the power supply, TI recommends to use a dedicate LDO or DCDC power supply for the MCU. A good load transient response performance is important for the ultrasonic application.
4. For the USS GUI connection, TI recommends to keep the I2C connection port (COMM_SDA, COMM_SCL and COMM_IRQ) on the board at first. To debug issues with USS GUI at the evaluation stage is easy.

4.1.2 Water Meter Schematic – MSP430FR6043 and MSP430FR5043

This is a highly integrated design using the MSP USS MCUs for water meter applications. For more details, refer to the TIDM-02005.

There are only a few points which need to be highlighted.

1. Before evaluating water meter applications on the EVM430-FR6043 board, there are changes that need to be made on the board to fit for water meter applications. Refer to the *Hardware Modifications for Water Meter Operation* section in the Optimized Ultrasonic Sensing Metrology Reference Design for Water Flow Measurement design guide.
2. For the USSXT, TI recommends to choose the load capacitor value through Equation 10.

$$C_{crystal} + C_{load} + C_{layout} = 34pF \tag{10}$$

   Since the ADC approach is used in the USSLib, the measurement accuracy is barely affected by crystal oscillator accuracy. Therefore, use a resonator on the EVM boards for demonstration with good performance. A resonator also consumes less current than a crystal. If users do not care about the current consumption and have a wide temperature range in the application, then users can consider using a crystal to replace the resonator. Users need to modify the USS_HSPLL_INPUT_CLK_TYPE and USS_HSPLL_USSXTAL_SETTLING_USEC in the software.
3. For the CHx_IN, OUT circuit, TI recommends to use 1% resistors and 1% NP0 capacitors for a better USS performance. Users can change the value of the resistor and capacitor if this can help to get a better performance on the meter. As a note, TI tested several combinations with different transducers and took the value with 200Ohm and 1000pF for the best performance.
4. For the power supply, TI recommends to use a dedicate LDO, DCDC power supply for the MCU. A good load transient response performance is important for the ultrasonic application.
5. For the USS GUI connection, TI recommends to keep the I2C connection port (COMM_SDA, COMM_SCL and COMM_IRQ) on the board at first. To debug issues with USS GUI at the evaluation stage is easy.
6. For evaluating with MSP430FR5043, the default MSP430FR5043 linker file must be modified to meet the memory configuration required for the USS library. Please uses the one lnk_msp430fr6043.cmd in the

MSP430FR6043EVM_USS_Water_Demo. Change the name to FR5043 and start evaluation. A comparison of the linker file is shown in Figure 4-1.

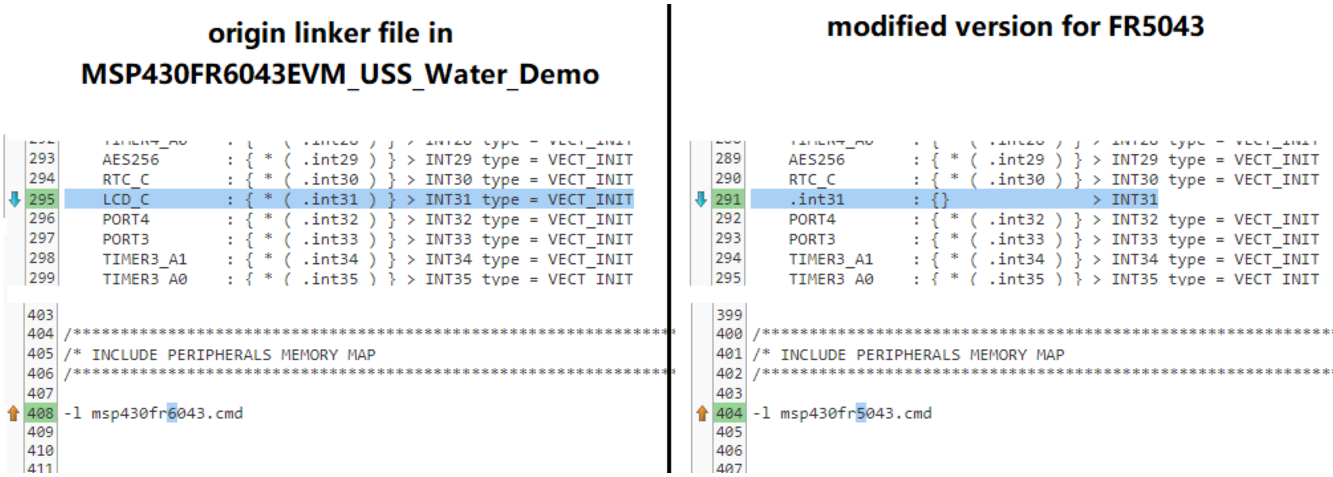

Figure 4-1. Linker File Differences on Water Meter Demo for MSP430FR5043 MCU

The MSP430FR5043 does not support LCD module, so the software must be modified to disable the LCD and any related functions. This is handled in hal_lcd.h.

4.1.3 Gas Meter Schematic – MSP430FR6043 and MSP430FR5043

For gas meter applications, use an external AFE circuit with MSP USS MCUs for the hardware design. For more details, refer to the TIDM-02003.

There are several points which need to be highlighted.

1. For evaluating gas meter applications on EVM430-FR6043 board, only use the channel CH0 for both UPS and DNS signal path. The analog switch U7 and U8 are used to switch the direction on the UPS and DNS signal. This can give a better ZFD performance compare to using both CH0 and CH1 channels.
2. Note that R10, R13 and R14 are essential for the hardware design. Do not forget these.
3. The U9 SN74LVC2T45 is a voltage level shifting component. This level shifts the excitation signal voltage to 5V, and improves the measurement performance in strict test environments. By default, the 5V LDO is bypassed on the EVM board. Users can add a jumper on the JP1 5VENA, and move the jumper on the JP2 from 3.3VTX to 5VTX. Find the predefined symbols in the Project Properties->Build->MSP430 Compiler->Predefined Symbols. Then, change the predefined symbol __AFE_EXT_3v3__ to __AFE_EXT_5v0__ to enable the 5V excitation function.

   Users can also remove this U9 on the board. The reference circuit without the U9 is shown in Figure 4-2. Note that R47 and R49 are kept in the circuit.

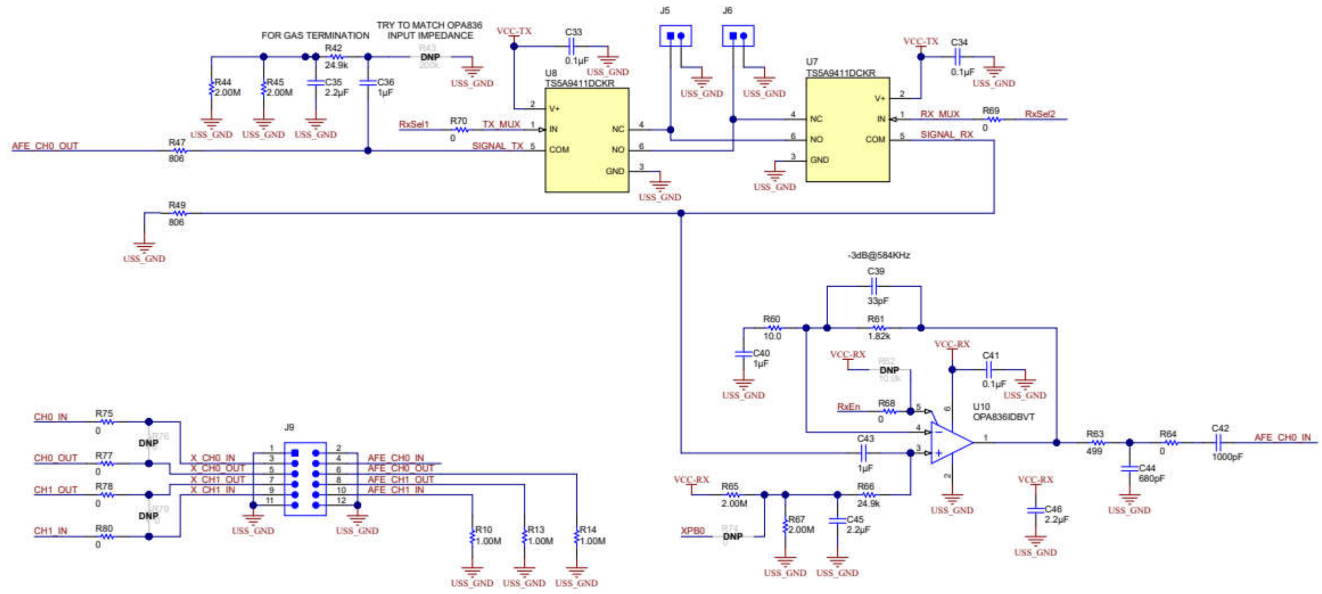

Figure 4-2. A Schematic Without Level Shifter

4. For the U10 OPA836, TI is recommends to use the same circuit as shown in the EVM board. The bandwidth -3dB at 584kHz is from the TINA simulation based on the *Low-Power Applications and the Effects of Resistor Values on Bandwidth* section of the OPAx836 Very-Low-Power, Rail-to-Rail Out, Negative Rail In, Voltage-Feedback Operational Amplifiers data sheet. This circuit is a general recommendation circuit for both 200kHz, 400kHz and 500kHz transducers. Users can change the circuit based on the design.

   R65, R67, R66 and C45 provide a bias voltage for the OPA IN+ input. Users can also find the R44, R45, R42 and C35 showing as the symmetric matching circuit on the CH0_OUT trace.

   R63 and C44 provide a low pass filter on the OPA_OUT pin before the signal goes into the MCU.

   OPA838 is a pin-to-pin replacement for the OPA836. OPA838 has a better input voltage noise performance rather than the OPA836. OPA838 can provide enhanced standard deviation performance up to 2.5x lower than the OPA836 and is a drop-in replacement. For more information, refer to TIDM-02003.
5. For the power supply U4, U5 and U6, TI recommends to use a dedicate LDO, DCDC power supply for the MCU. A good load transient response performance is important for ultrasonic applications. When users do not need the 5V feature, the U5 5V DCDC is not necessary in the board. Users can also use one LDO to provide both VCC_TX and VCC_RX to save BOM value. This needs to connect the TxPwr and RxPwr together on the hardware for the changing or change the configuration in the software to save one GPIO.
6. For the USSXT, TI recommends to choose the load capacitor value by using Equation 11.

$$C_{crystal} + C_{load} + C_{layout} = 34pF \tag{11}$$

   Since the ADC approach is used in the USSLib, the measurement accuracy is barely affected by the crystal oscillator accuracy. Therefore, use a resonator on the EVM boards for demonstration with good performance. A resonator also consumes less current than a crystal. If users do not care about the current consumption and have a wide temperature range in the application, then users can consider to use a crystal to replace the resonator. Users need to modify the USS_HSPLL_INPUT_CLK_TYPE and USS_HSPLL_USSXTAL_SETTLING_USEC in the software.
7. For the CHx_IN, OUT AFE circuit, TI recommends to use 1% resistors and 1% NP0 capacitors for a better measurement performance. For more details, refer to the EVM bill of materials list.
8. For the USS GUI connection, TI recommends to keep the I2C connection port (COMM_SDA, COMM_SCL and COMM_IRQ) on the board at first. To debug issues with USS GUI at the evaluation stage is easy.
9. For evaluating with MSP430FR5043, the default MSP430FR5043 linker file must be modified to meet the memory configuration required for the USS library. Use the lnk_msp430fr6043.cmd in the MSP430FR6043EVM_USS_Gas_Demo. Change the name to FR5043 and start evaluation. The

MSP430FR5043 does not include LCD support, so the software must be modified to disable the LCD and any related functions. This is handled in hal_lcd.h.

4.2 PCB Layout Guide

General PCB guidelines need to be followed to make sure of accurate measurements and proper operation.

1. Decoupling capacitors must be placed close to the supply pins.
2. Oscillators must be placed close to the chip and use a separated ground plane from the main ground plane. These components be tied to the main ground with a small connection as shown in Figure 4-3. A good ground layout for the crystals can help on getting a higher ESD grade.

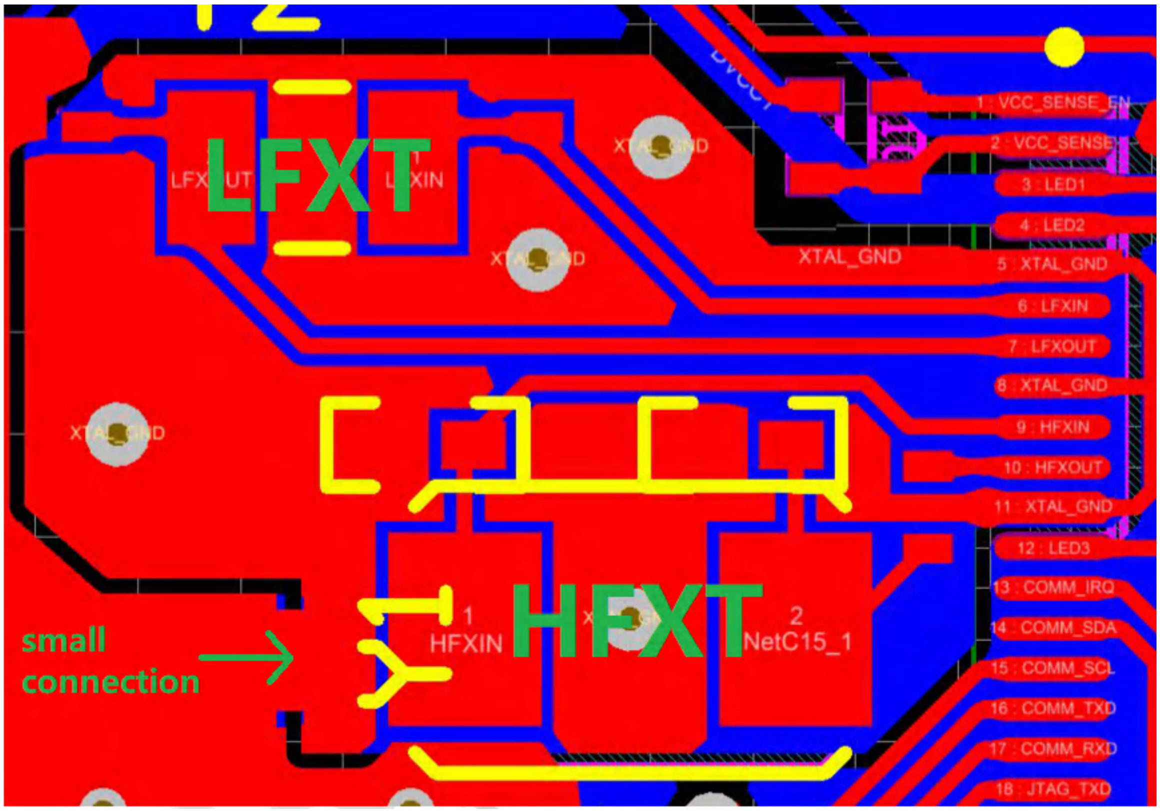

Figure 4-3. Oscillator Layout Example

3. Traces for USS CH0_IN, CH0_OUT, CH1_IN, and CH1_OUT must be matched in length to make sure of proper timing of signals because these are in the picosecond range, as shown Figure 4-4.

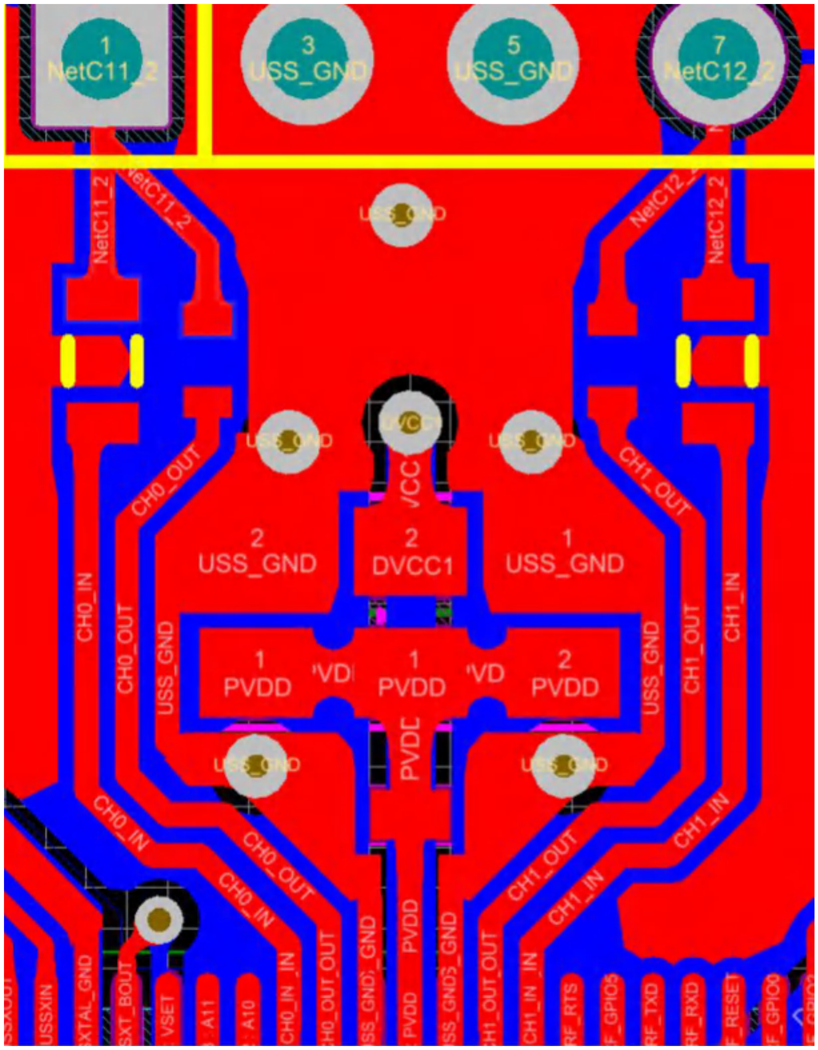

Figure 4-4. USS Signal Layout Example

4. 1% component tolerance must be used for all USS signal components for highest accuracy.
5. Make sure that no traces are crossing the USS signal on other layers.
6. LCD connections must be made following the guidelines in the Designing With MSP430 and Segment LCD application note.

5 Software Design Guide

TI provides the USS library and USS Design Center to help users integrate with the application software for ultrasonic flow meters development.

5.1 USS Demo Projects and Related Resources

The software resources for water meter and gas meter applications are similar. Users can find all the software resources for water meter application at USS-SWLIB-WATER. Software resources for gas meter applications are in this USS-SWLIB-GAS.

Figure 5-1 shows what includes in the resource link.

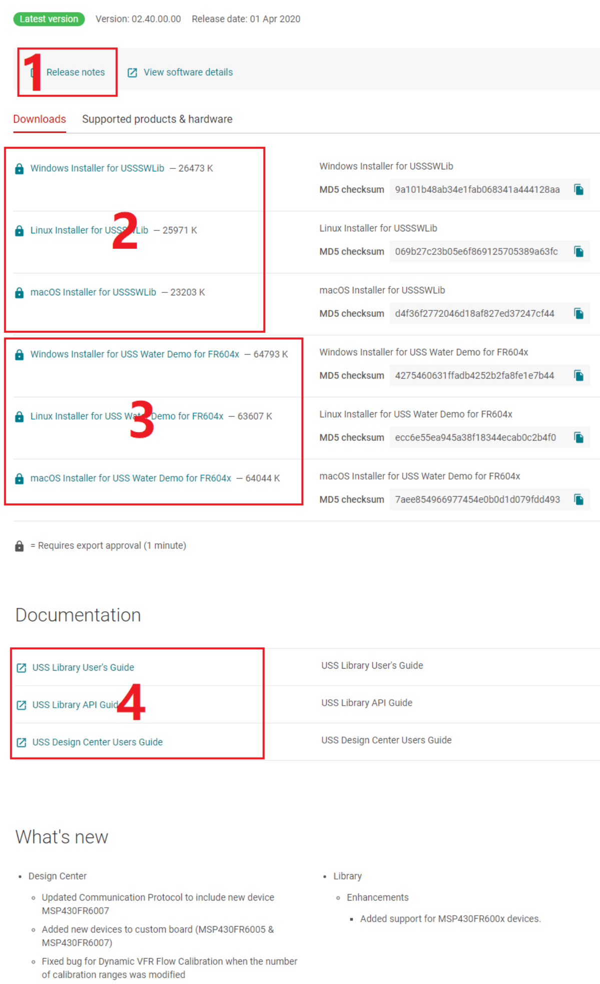

Figure 5-1. USS Software Resource Page

1. The first part is the release notes. Users can find the updates of the current version of the demo code. This also includes the revision history, installation and usage and other basic information for the demo project.
2. The second part is the USSSWLIB installers. This includes the USS Design Center (USS DC) and a template example project.

   The template example project includes the full processes of the USS measurement. However, this does not include the USS DC communication interface. By using this template example project, users can measure the flow but cannot connect to the USS DC. If the user has passed the evaluation stage and has a GUI interface, then users can use the template example as a start for a project.
3. The third part is the demo example project. This is recommended for the users to start evaluation with. This includes the full processes of the USS measurement and the USS DC communication interface. The USS DC is very useful in the early evaluation stage, and can help users to log data and analyze easily.

4. The fourth part is the documents.
   a. The USS Library User's Guide includes everything users need to know about the USS library. Some frequently asked questions are answered in this document.

      For example, the resources used are described in the USS library in the Code Examples->Hardware Prerequisites->Device Resource Usage.

      To check updates in the table coefficients for the absTOF interpolation calculation, see the *Generating Interpolation Correction Look-up Table* section. For the Lobe algorithm, this table is used for the calculation of peak value of each lobe. Using a higher interpolation can improve the absTOF accuracy.

      About optimized library, users can check the memory usage information for different USS libraries. This also includes how to implement the optimized library in the using the *Memory Optimized Libraries* section.
   b. In the USS Library API Guide, there are detailed introduction for each API in the USS library.
   c. The USS Design Center Users Guide includes everything users need to know about the USS DC including Configuration, Waveform Plots, ADC Capture Functionality, Frequency Sweep, Calibration, Debug Waveform and Error Handling. Some frequently asked questions are answered in this document.

      Users can check in the *Error Handling* section for more information on how check the reported error information.

      Users can check the *Communication Protocol Spec* section on how to build the GUI based on the current communication protocol.

5.2 Demo Project Instruction

5.2.1 Files in Demo Project

Figure 5-2 shows what includes in an USS demo project.

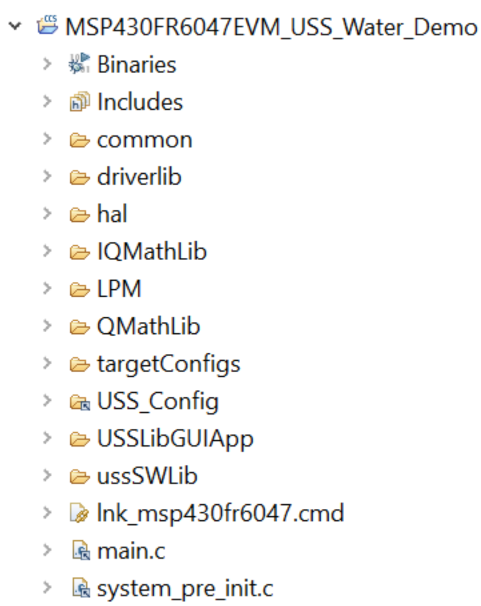

Figure 5-2. Files in Demo Project

1. Common folder: this includes the USS DC drivers, protocol, utility and command handler. Use one I2C port and an interrupt pin for the communication between the MCU and USS DC. Also prepare an UART interface in this part of code. This can be used for users to build a GUI. Currently, the USS DC does not support using UART communication.
2. Driverlib folder: this includes the driver library for the MSP430 peripherals.
3. Hal folder: the hal_adc includes hardware abstraction layer for ADC functions such as using the integrated 12bit SAR ADC for internal temperature sensor capture and external input voltage capture. The hal_lcd

includes hardware abstraction layer for FH-1138P segmented LCD. The hal_system includes hardware abstraction layer for MSP system including clocks, watchdog and GPIOs. The hal_uart includes hardware abstraction layer for UART communication.

4. IQMathLib and QMathLib folder: the MSP IQmath and Qmath Libraries are a collection of highly optimized and high-precision mathematical functions for C programmers to seamlessly port a floating-point algorithm into fixed-point code on MSP430 and MSP432 devices. These routines are typically used in computationally intensive real-time applications where best execution speed, high accuracy and ultra-low energy are critical. By using the IQmath and Qmath libraries, users can achieve execution speeds considerably faster and energy consumption considerably lower than equivalent code written using floating-point math.
5. USS_Config folder: all modifications to USS SW library are contained in USS_userConfig.h. The USS_userConfig.c contains all temporary buffer used by the library. The lookup tables are used for interpolation method used in the USS library. The calibration header file contains the flow rate calibration data. Users can use USS DC to generate all these header files with custom configuration for certain applications. Then, replace the original one in the project and rebuild and program the project with the new generated header files. MCu does not need to reconfigure these parameters for tests this way.
6. USSLibGUIApp folder: this folder handles the interaction between USS library and USS DC. The main loop of the project also handles in USSLibGUIApp.c. Users can add an application code in main loop.
7. UssSWLib folder: this folder contains the USS library and the header file. The ussSwLib.h header file contains all USS library enums, structs, macros, function and global variables definitions. The comments in this header file are also very important for the users to have a better understanding of each variable.
8. Linker file: the lnk_msp430fr6047.cmd tells compiler where to put the program, data and other things like interrupt vectors in the MSP430 memory space. The linker file in the demo project has been modified to fit the requirement of USS library.

5.2.2 Properties Setting in Demo Project

- Optimization level: by default, the demo project uses optimization level 3. TI does not recommend to change the optimization level of the project. If users need more code size for the application code, then check the information of the optimized library in the USS Library User's Guide.

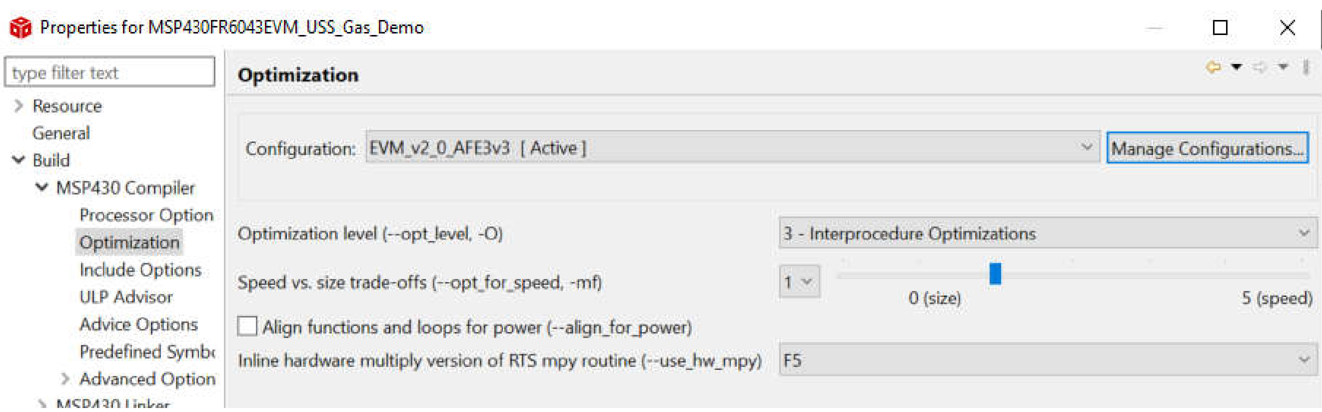

Figure 5-3. Properties Setting in Demo Project

- Predefined symbols: the predefined symbols are predefined by the compiler system. This can be found in Project Properties->Build->MSP430 Compiler->Predefined Symbols. If users need to enable the 5V excitation function, then change the predefined symbol __AFE_EXT_3v3__ to __AFE_EXT_5v0__ to enable. Refer to Section 4.1.3 for more details.

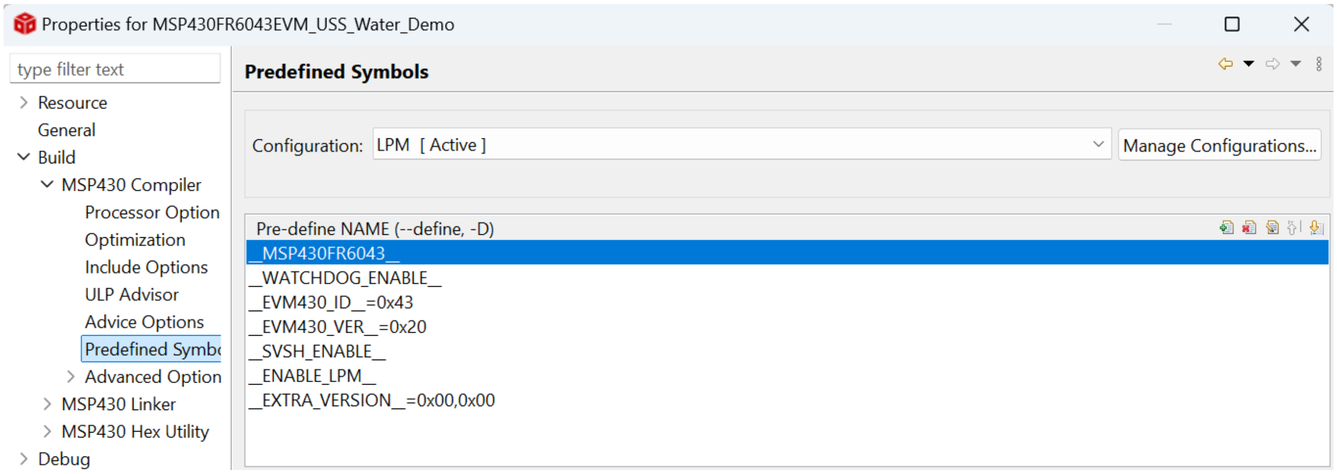

Figure 5-4. Predefined Symbols

6 Summary

This application note provides a clear explanation on the TOF calculation method. When there are any error results coming from the USS library, users can modify the parameters to avoid error results with a better understanding of the calculation process.

This document helps beginners to start with the USS design from both the hardware side and software side. This application note guides users to build up a meter.

7 References

- Texas Instruments, MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide
- Texas Instruments, MSP Ultrasonic Sensing Users Guide
- Texas Instruments, Ultrasonic Sensing Solution Design Center User Guide

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