TI Designs
Ultrasonic Water Flow Measurement

Design Overview

This Ultrasonic Water Flow Measurement system is ideal for providing highly accurate measurement across wide-flow ranges as low as 1.4 GPM. The design is based on a single MCU with discrete analog components. The design uses a unique propriety algorithm that improves robustness and performance in flow measurement across a wide range of operating conditions. This design is fully compatible with TI RF plug-in evaluation modules for wireless advanced metering infrastructure (AMI) networks.

Design Resources

TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT	Tool Folder Containing Design Files
MSP430FR6972	Product Folder
SN74LVC2T45	Product Folder
THS4521	Product Folder
TS5A63157	Product Folder

TI E2E™ Community

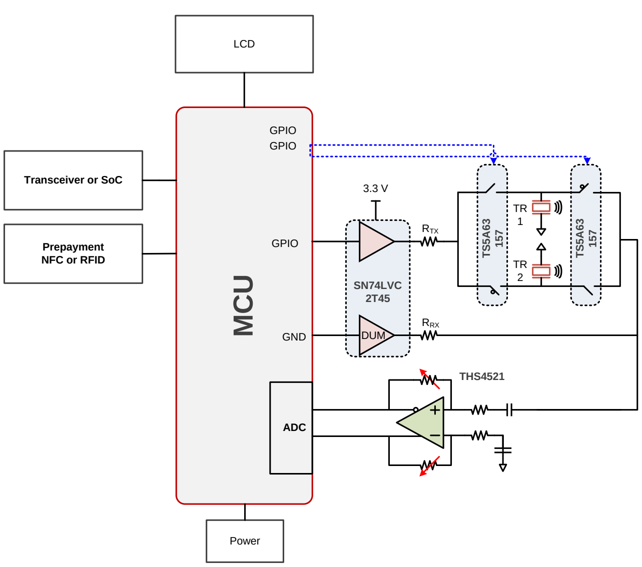
ASK Our E2E Experts
WEBENCH® Calculator Tools

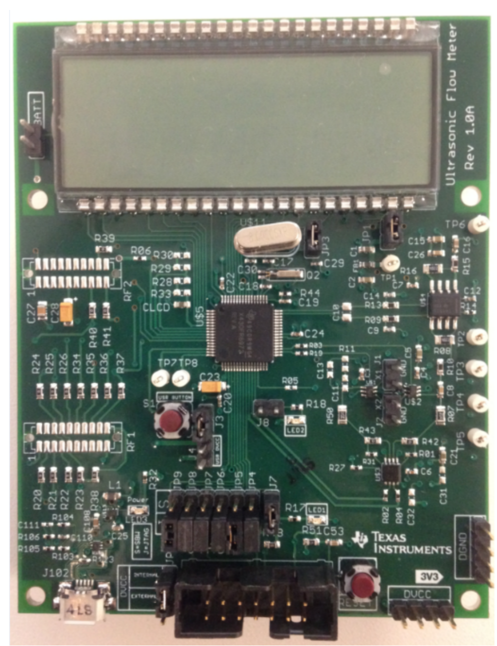
Design Features

- Ultra-Low Power − Approximate 20-Year Lifetime With Battery
- Analog-to-Digital Converter (ADC)-Based Approach Meets ISO 4064-1 EEC Applicable Norms
- Robust to Signal Amplitude Variations – Insensitive to Received Signal Amplitude
- Allows Low-Power Implementation With Optimized Signal Processing
- Supports Sub-1GHz and 2.4-GHz RF Wireless Communication Modules
- Support for Low-Power Segment Liquid-Crystal Display (LCD) Controller

Featured Applications

- Water Meter





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 System Description

The reference EVM design for the Ultrasonic Flow Meter comprises a 12-bit ADC and LCD controller on a TI MSP430FR6972™ MCU, discrete analog front-end (AFE) components, and a transducer.

The EVM consists of the MSP430FR6792 MCU with integrated LCD support, an RF module socket, discrete AFE circuitry, headers to connect the transducer, a AAA battery holder, and a 14-pin Joint Test Action Group (JTAG) header.

This system is a low-power design using the latest TI MCU MSP430FR6972 with FRAM to store the programming code. The system block diagram shows all the elements that the EVM has and the potential add-on modules, like the RF sub-system, near-field communication (NFC) module, or the radio-frequency identification (RFID) module that can be connected to the EVM.

The discrete AFE circuitry comprises a dual-bit, dual-supply bus transceiver; a single-pole, double-throw (SPDT) analog switch; and a very-low power, fully differential operational amplifier (op-amp). The slow meter solution is based on a differential time of flight estimation with involving two transducers for upstream and downstream paths. The signal waveforms are transmitted between two adjacent transducers (Transducer A and Transducer B). Transducer A transmits an upstream path signal that Transducer B receives. The flight time for the signal can be calculated using the known velocity of sound and length between the transducers. Transducer B transmits a downstream path signal to Transducer A and calculates the time of flight. The upstream and downstream waveforms are then processed on the main MCU to obtain the volume. The benefits of this solution are: naturally obtaining the envelope of signal through ADC-based processing, provision of bubble detection features, and a robust response to signal amplitude variations.

2 Block Diagram

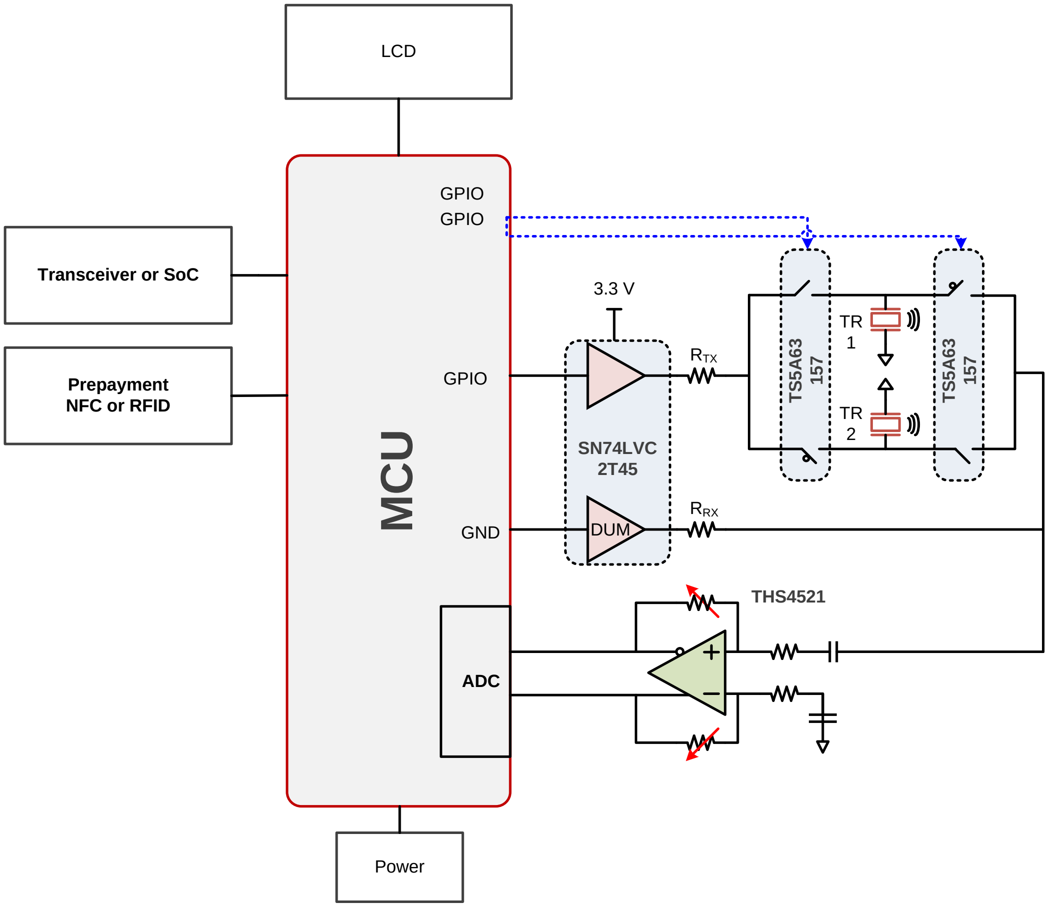


Figure 1. TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT System Block Diagram

2.1 Ultra-Low-Power Microcontroller

The MSP430FR6972 is an ultra-low-power MCU that has an FRAM of up to 64 KB for code and data. Peripherals include RTC, ADC12, CRC, code security and encryption, MPY32, eUSCI for communication, an LCD, and timers.

2.2 Dual-Bit Dual-Supply Bus Transceiver

This dual-bit non-inverting transceiver is used for asynchronous communication between two data buses. The logic levels of direction-control input activate either B-port or A-port outputs. The device transmits data from the A-bus to the B-bus when the B-port outputs are activated; alternatively, the device transmits data from the B-bus to the A-bus when the A-port outputs are activated.

2.3 SPDT Analog Switch

The TS5A63157 is a single-pole, double-throw (SPDT) analog switch designed to operate from 1.65 V to 5.5 V and is used to switch between two data paths.

2.4 Differential Amplifier

The THS4521 device is a fully differential op-amp with a rail-to-rail output. These amplifiers are used for low-power data acquisition systems and high-density applications. Additionally, these devices are ideally suited for driving ADCs using only a single 2.5- to 5-V voltage and ground power supply.

3 System Design Theory

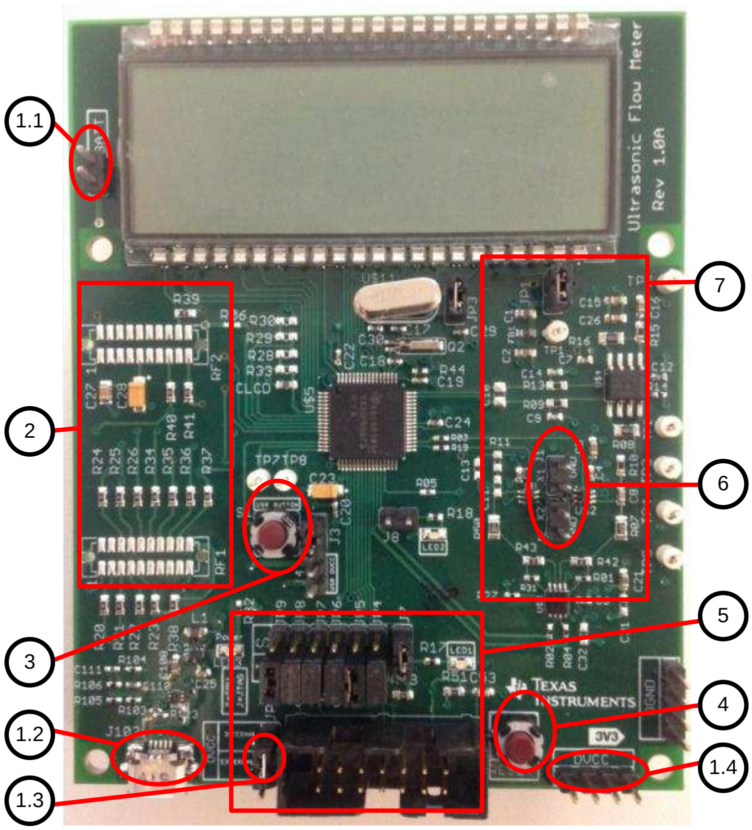


Figure 2. EVM Board

The main board comprises an MSP430FR6972 MCU with an LCD display. The board powers either through an external DC-DC supply, JTAG, battery, or USB to provide 3.3 V. The board can divide into multiple parts for the use of developing flow meters with RF capabilities. Refer to Table 1 for a description of the board layout.

Table 1. Description of Main Board Layout

PART	DESCRIPTION
	Power supply options to power main board
1.1	Jumper setting to power board through AAA batteries
1.2	USB connection to PC to power board
1.3	Jumper setting to power board through JTAG
1.4	External 3.3-V DC-DC supply
2	A socket for RF modules of sub-1 GHz or 2.4 GHz or RFID, connecting to the MCU with SPI, universal asynchronous receiver and transmitter (UART), and I/O
3	Push-button switch to implement key control
4	Reset button − this board does not have an on or off switch; to restart, push the reset button
5	JTAG interface to connect to board
6	Headers to connect external transducers
7	Analog front-end layout section

The core component of the layout is the AFE and the user must carefully route this section of the board. TI recommends ensuring that the trace lengths of signals in the analog section of the board are symmetrical and short. Figure 3 highlights a section of the layout with an example of symmetrical trace lengths.

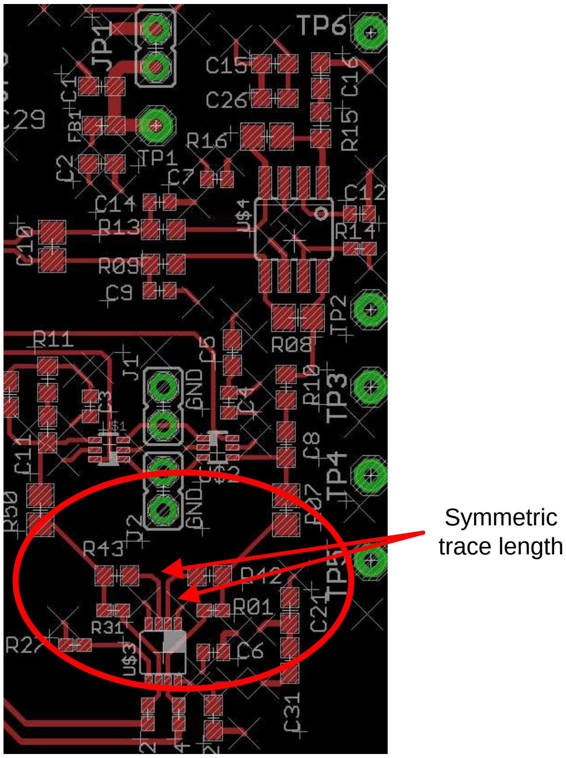


Figure 3. Design Layout – Analog

4 Test Setup

The following procedure details the testing of the board (note that the test firmware is pre-programmed on the main board). For more details on downloading the firmware onto the MSP430 device, refer to Section 2 of following TI Wiki: *Generating and Loading MSP430 Binary Files*.

1. Analyze the impedance of each Audiowell transducer by connecting the test fixture to a precision impedance analyzer. The resonant frequency of Audiowell transducers used in the test setup is 1 MHz.
2. Place jumpers on the main board on:
   - JP1 – provides power to AFE circuitry
   - JP3 – external crystal
   - JP4, JP5, JP6, JP7, JP8, and JP9 – JTAG debugger
3. Connect the Audiowell transducers to jumpers J1 and J2 as Figure 4 shows. This test setup uses a brass pipe developed by Audiowell.

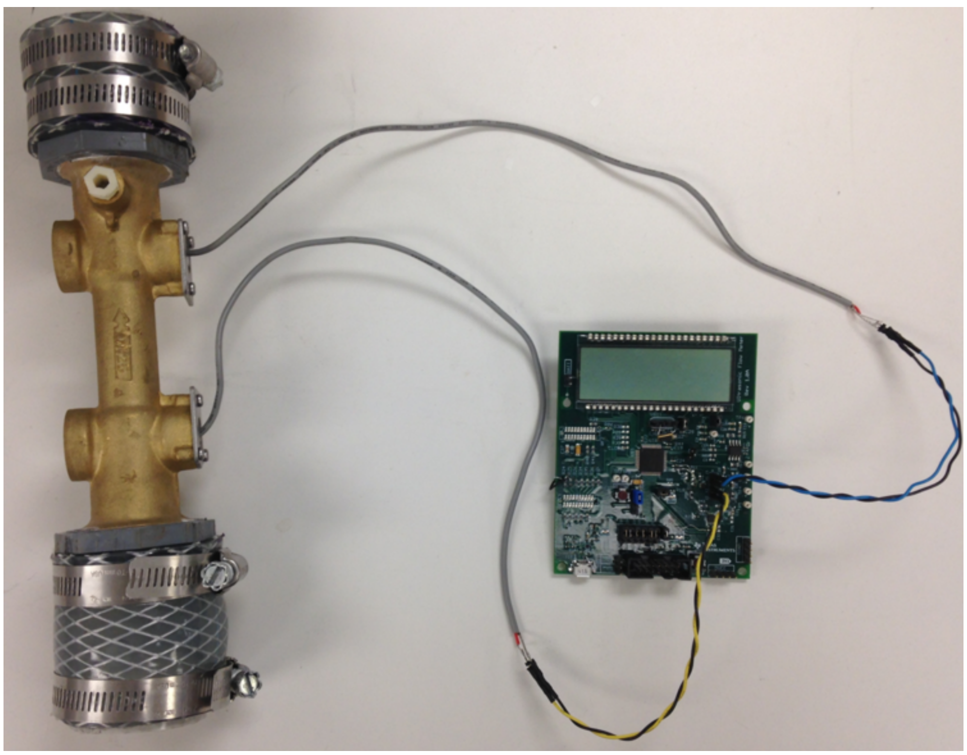


Figure 4. Transducers Connected to Main Board

   For more information on Audiowell, visit the product page: http://www.audiowell.com/en/product-detail.aspx?id=80.

4. Power the board by connecting an external 3.3-V DC supply to the DVCC header and DGND header, as Figure 5 shows. The LED3 (power) on the board turns ON to indicate that the board was powered successfully.

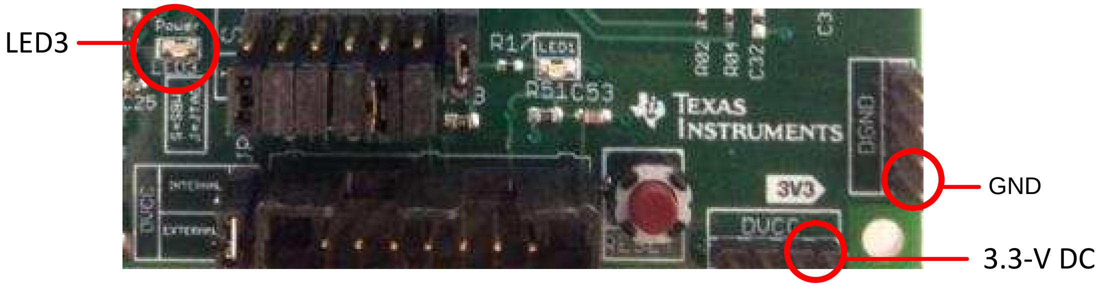


Figure 5. External DC Supply Connections

5. As Figure 6 shows, connect the probe onto the pad of C10 shows and verify the signal on the scope. See Figure 7 for a scope capture of the signal.

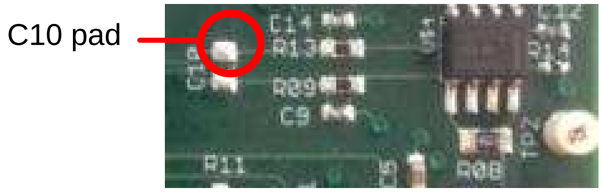


Figure 6. Probe C10 Pad

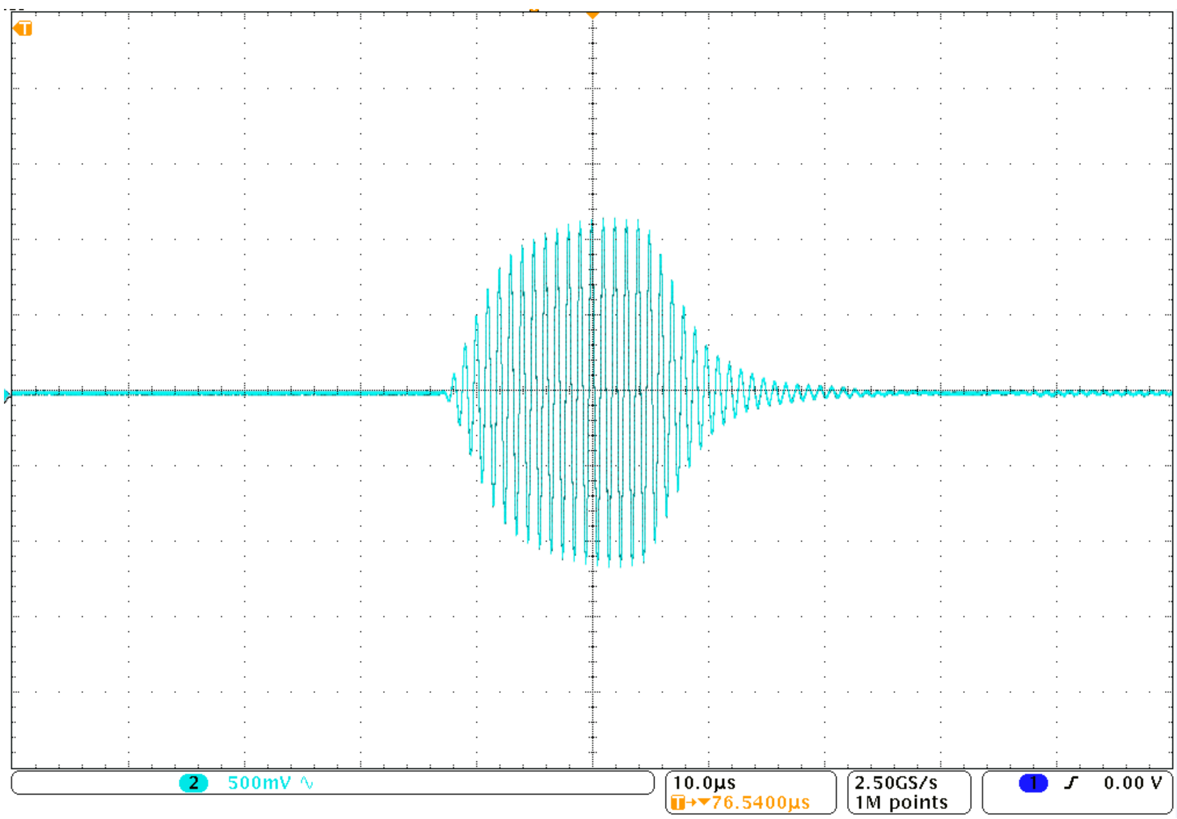


Figure 7. Signal Scope Capture

6. Steps 1–5 validate the signal path of the system with an Audiowell model. The next step is to connect the board to a flow setup to measure the volume of water in gallons per minute. Figure 8 shows a block diagram of the flow setup. This setup utilizes a water reservoir with a motor pump to pump water. The motor offers manual or automatic controls to obtain the desired flow rate. In Figure 8 section the main board and the Audiowell model is connected to test the setup with a reference flow meter. Take care to ensure zero leakage occurs in the flow setup.

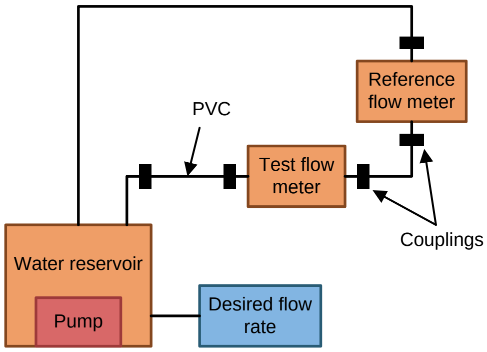


Figure 8. Flow Meter Test Setup

7. While varying the desired flow rate, the LCD displays in Figure 9 and Figure 10 show the volume of water of the test flow meter (in gallons/min).

Figure 9. Volume Displayed on LCD

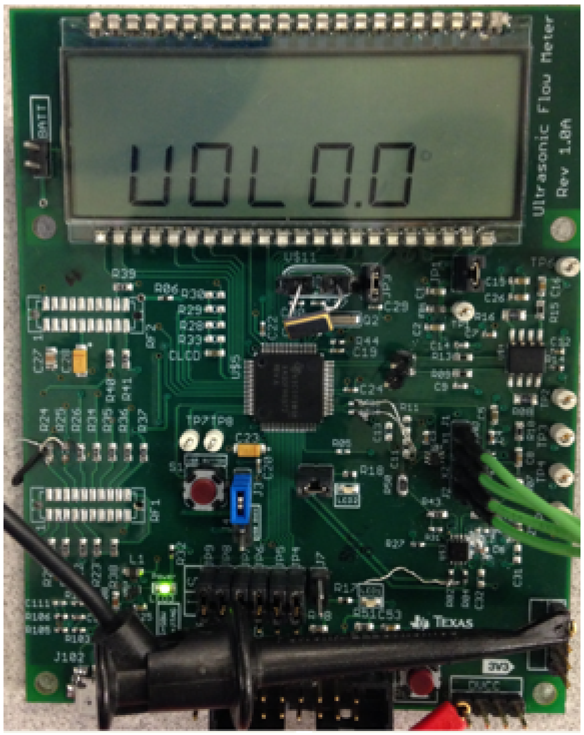


Figure 10. Zero Flow Volume

5 Test Data

Figure 11 shows the volume of water computed by the main board with an Audiowell model connected across varying desired flow rates. The test results were captured by varying the flow of water multiples times throughout the day to validate the system across time and temperature. The accuracy error of the system was approximately 1% based on the captured test data.

The zero flow drift at room temperature across time is very low for this system and the standard deviation for a single shot measurement is < 25 ps. The current consumption of the system is approximately 20 uA.

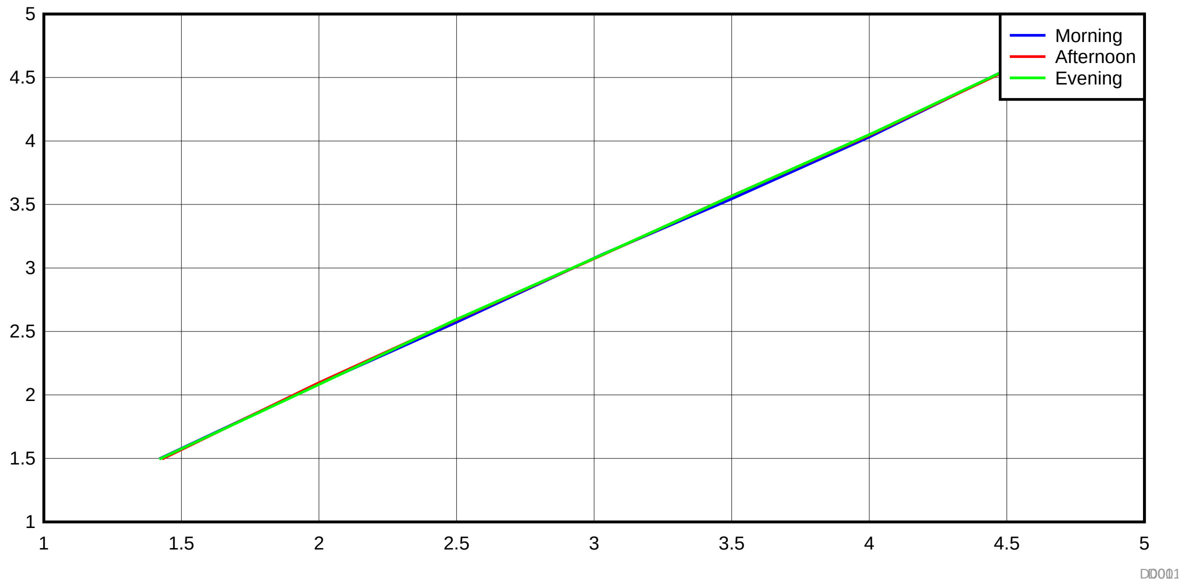


Figure 11. Test Results

6 Design Files

6.1 Schematics

To download the schematics for each board, see the design files at TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT.

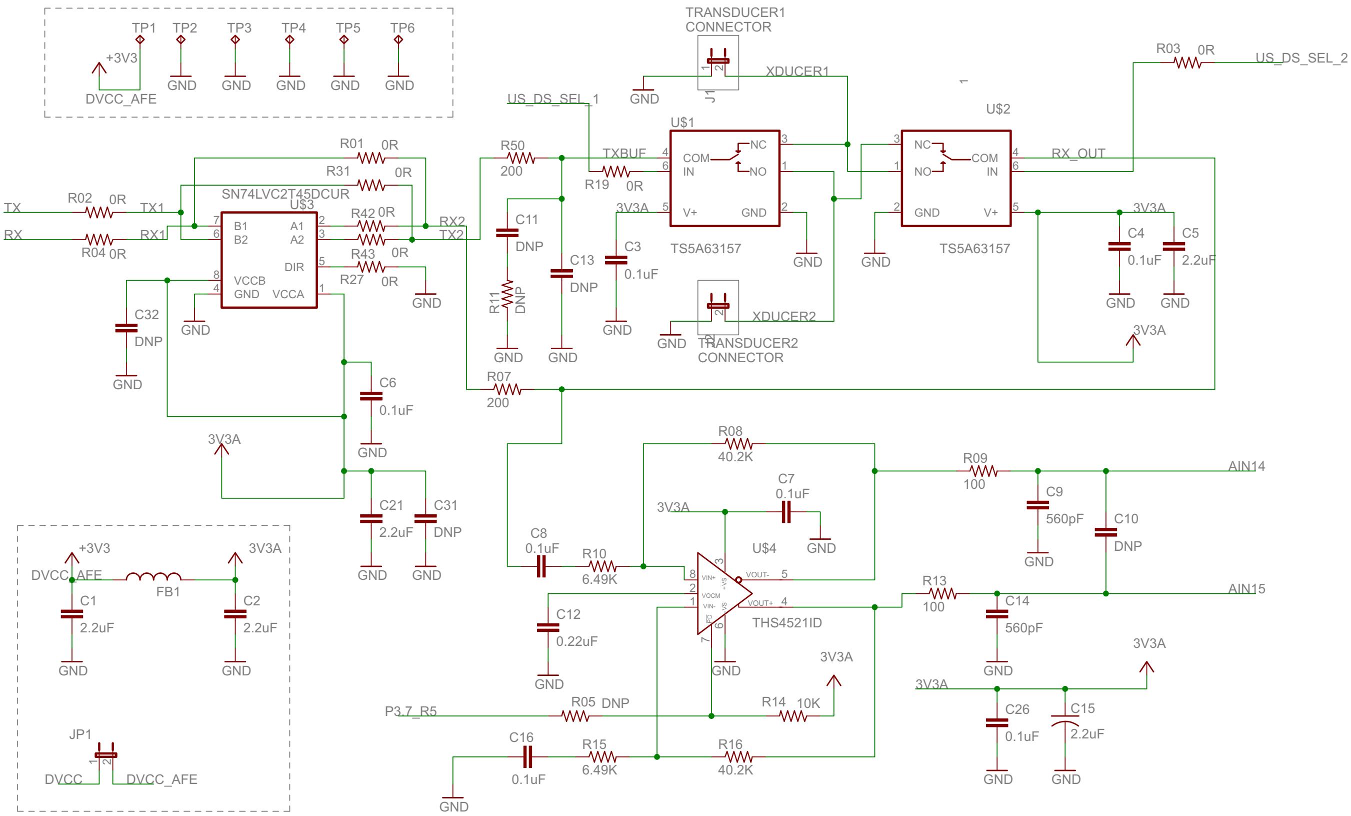


Figure 12. Schematics Page 1

6.2 Bill of Materials

To download the bill of materials (BOM) for each board, see the design files at TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT.

6.3 Layout Prints

To download the layout prints for each board, see the design files at TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT.

6.4 Eagle Project

To download the Eagle project files for each board, see the design files at TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT.

6.5 Gerber Files

To download the Gerber project files for each board, see the design files at TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT.

6.6 Assembly Drawings

To download the assembly drawings for each board, see the design files at TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT.

6.7 Software Files

To download the software files, see the design files at TIDM-ULTRASONIC-WATER-FLOW-MEASUREMENT.

7 References

1. Texas Instruments, *TI E2E™ Community*, Online Engineer Community, http://e2e.ti.com/

8 About the Author

NAVEEN KALA is a system applications engineer at Texas Instruments, where he is responsible for providing technical support and training on Smart Grid solutions and driving solutions for Smart Grid/Metering, and working on defining future requirements in roadmap. He received the M.Eng. degree in electrical and computer engineering from the University of Iowa.

Revision A

Changes from Original (June 2015) to A Revision **Page**

- Changed title from *Ultrasonic Water Meter Design Using Time-to-Digital Conversion* to *Ultrasonic Water Flow Measurement*.......... 1

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