TIDA00322: Design Overview

Description:

TI reference design TIDA00322 is an automotive Liquid Level and Fluid Identification measurement system. It is based on the dual channel TDC1000-Q1 Ultrasonic AFE and the Real-Time Microcontroller C2000. This reference design can also be used with the TDC1000 for industrial/consumer applications.

While the TIDA00322 is an excellent reference design, it is not recommended for initial product development since it has limited accessibility to signals that would be needed for initial product development. For automotive designs, it is recommended to begin with the TDC1000-C2000EVM (http://www.ti.com/tool/tdc1000-c2000evm). Since the GUI is the same for the EVM and the TI Design, one can easily migrate to the TI Design after initial evaluation is complete. For industrial or consumer designs, it is recommended to begin with the TDC1000-TDC7200EVM (http://www.ti.com/tool/tdc1000-tdc7200evm). This EVM has the ability of using the MSP430 or the TDC7200 as the stop-watch timer; usage of each depends on the time of flight accuracy requirement of the application.

Features

- Dual Channel Analog-front-end for ultrasonic sensing
- High voltage circuit to drive the transducer with 30V to penetrate deeper tanks
- Input voltage range of 6V to 40V with reverse battery protection
- Automotive qualified Bill of Material
- External RTD Measurement to monitor temperature changes that affect the medium's speed of sound
- CAN transceiver for flexibility of adding future CAN stack

TDC1000-Q1: Ultrasonic AFE Overview

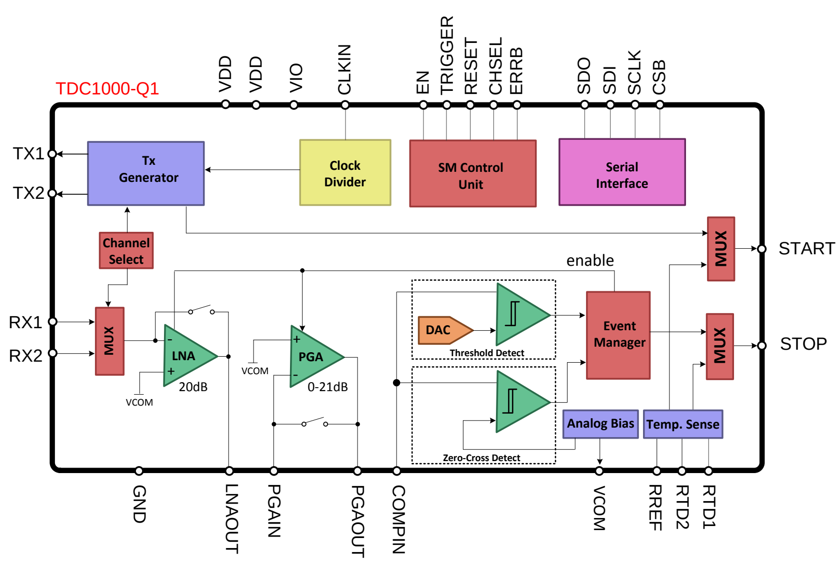

Figure 1 - TDC1000 block diagram

The TDC1000-Q1 is the ultrasonic analog-front-end (AFE) that is responsible for driving the ultrasonic sensor, also known as transducer. As seen in the block diagram above, the TDC1000 has a Transmit path and a Receive path.

The Transmit path has the ability to excite the transducer with 1-31 pulses from 31.25kHz to 4MHz. The more pulses you excite the sensor, the higher the chance you will be able to see the echo. For this design, we recommend exciting the transducer with 4 pulses first, monitoring the echo seen at the receive pins (RX), then varying the number of pulses to get the desired result. The 31.25kHz to 4MHz frequency is set according to the medium. As a rule of thumb, since water has a higher speed of sound of 1480 m/s at 25°C, the typical excitation frequency for water is 1MHz. For air, whose speed of sound is 343 m/s at 25°C, the typical excitation frequency is 40kHz, and for gas, it is typically 200kHz. For this design, we recommend STEMiNC's 1MHz sensor (part number: SMD10T2R111) for water fluid.

A typical voltage to excite the transducer is 5V. However, for fluid applications where the tanks are quite deep, we recommend exciting the transducer with a higher voltage. For this reason, a high voltage (HV) driver circuit is needed to boost this 5V 50% duty cycle pulse wave to 30V. The design consideration for this circuit will be described in the next section.

Since the sensor has the ability to transmit and receive on the same pin, the transmit pin (TX) must be tied to the receive pin (RX). In this application, we chose to connect RX1 to TX2 via R38, as seen in Figure 2.

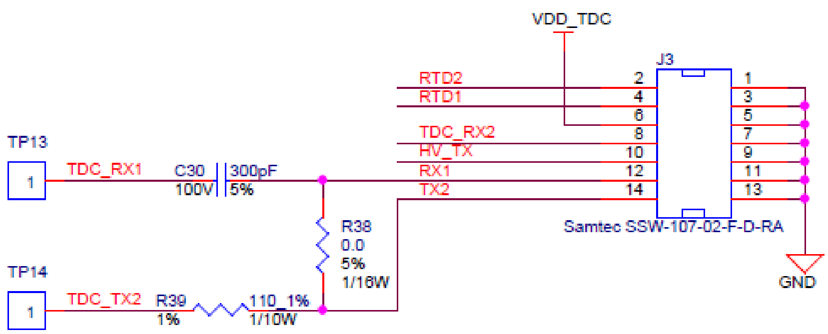

Figure 2 - RX1 and TX1 connection

The Receive path of the TDC1000-Q1 has the sole job of receiving the reflected wave (a.k.a echo) from the transducer. Once the echo is received, it is gained with a low-noise-amplifier (LNA) of 20 dB, and a programmable gain amplifier (PGA) of 0 to 21dB. Internally, the LNA has a feedback capacitor of 30pF and resistor of 9kΩ, as seen in the diagram below. Since the sensor frequency is 1MHz, the LNA needs to be placed in capacitive mode. This means that the input capacitance to the LNA should be around 300pF to get a gain of approximately 20dB for a 1MHz signal. For this reason, C20 and C30 on the EVM should have values of 300pF.

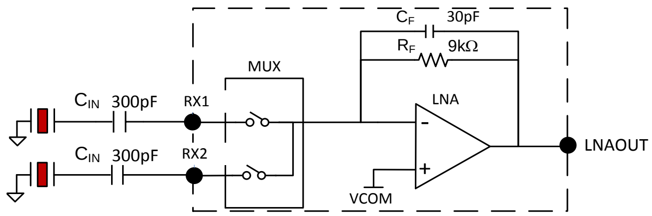

Figure 3 - LNA

Once the echo passes the LNA, it is again amplified by the PGA. There should be an external capacitor (typically 1nF) between the LNAOUT and PGAOUT to connect these amplifiers together. The gain of the PGA can be set using the TDC1000 register bit PGA_GAIN.

After the echo is amplified by the PGA, it is filtered by a band-pass-filter, as shown in Figure 4. The values of these filters are selected so that the 1MHz signal is allowed, and anything lower than 582 kHz or above 3.12MHz is suppressed.

Also note that the echo has to be DC bias by the VCOM (which isVDD/2). For this reason, all of the gain stages and the filter are also DC bias to VCOM.

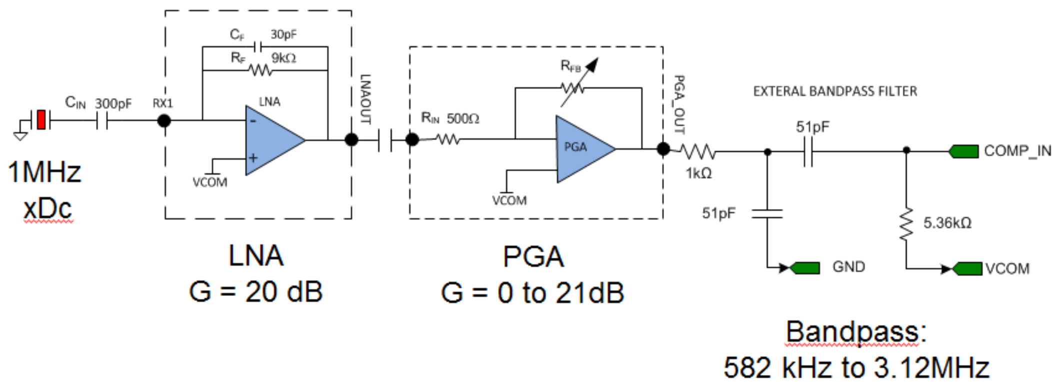

Figure 4 - Receive Signal Chain

The VCOM pin can be biased externally or internally. This is done via TDC1000 register bit VCOM_SEL. If an external bias is desired, we recommend connecting the VCOM pin to a resistor divider, as shown inFigure 5, to make sure it is half of VDD. A typical value for these resistors can be 4.99MΩ.

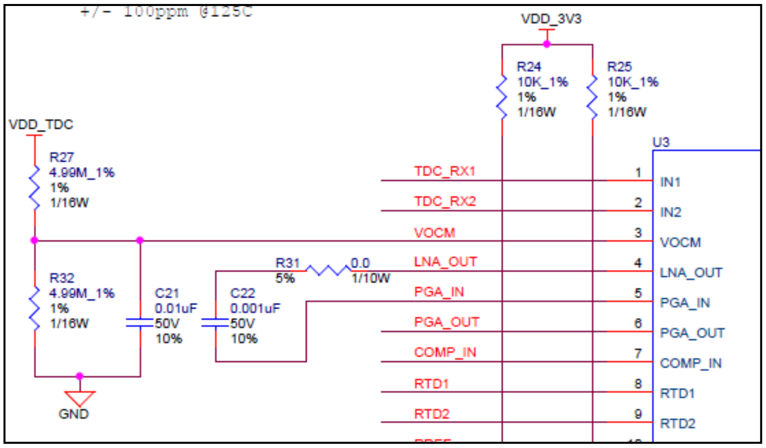

Figure 5 – External VCOM Design

Temperature sensing is very important in ultrasonic applications since the speed of sound changes due to temperature. To do temperature measurements, the TDC1000-Q1 provides external connections to two PT1000 or two PT500 RTDs. In addition, the system requires a temperature-stable external reference resistor (RREF). If the RTD type is PT500, then RREF should be 500Ω. If the RTD type is PT1000, then RREF should be 1 kΩ. RREF needs to have either a low temperature coefficient or be calibrated for temperature shift.

Fortunately, TDC1000's temperature sensor measurement can be performed without the need of an external ADC. The temperature sensor block operates by converting the resistances of RREF and the two RTDs into series of START and STOP pulses. The interval between the pulses is proportional to the measured resistances, and therefore, the temperature of the fluid. As shown in the figure below, the TDC1000 performs three measurements per trigger event and generates the corresponding pulses on the START and STOP pins.

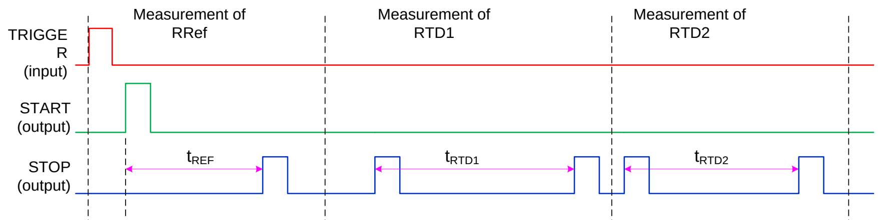

Figure 6 - Temperature Sensor Measurement

Once the three intervals are measured, the resistance of RTD1 can be determined by using the following equation: RTD1 = (RREF) * (t_{REF} / t_{RTD1}). Likewise, RTD2 can be calculated as: RTD2 = (RREF) * (t_{REF} / t_{RTD2}).

Board layout also needs to be considered for the TDC1000. We recommend the following layout rules:

- In a 4-layer board design, the recommended layer stack order from top to bottom is: signal, ground, power and signal.
- Bypass capacitors should be placed in close proximity to the VDD and VIO pins.
- The length of the START and STOP traces from the DUT to the stopwatch/MCU should be matched to prevent uneven signal delays. Also, avoid unnecessary via-holes on these

traces and keep the routing as short/direct as possible to minimize parasitic capacitance on the PCB.

- Match the length of the TX pair from the DUT to the transducers to prevent uneven signal delays from one channel direction to the other.
- Match the length of the RX pair from the transducers to the DUT to prevent uneven signal delays from one channel direction to the other.
- Match the length (or resistance) of the traces leading to the RTD sensors. PCB series resistance will be added in series to the RTD sensors.
- Route the SPI signal traces close together. Place a series resistor at the source of SDO (close to the DUT) and series resistors at the sources of SDI, SCLK and CSB (close to the master MCU).

An example layout for the TDC1000 can be seen in Figure 7.

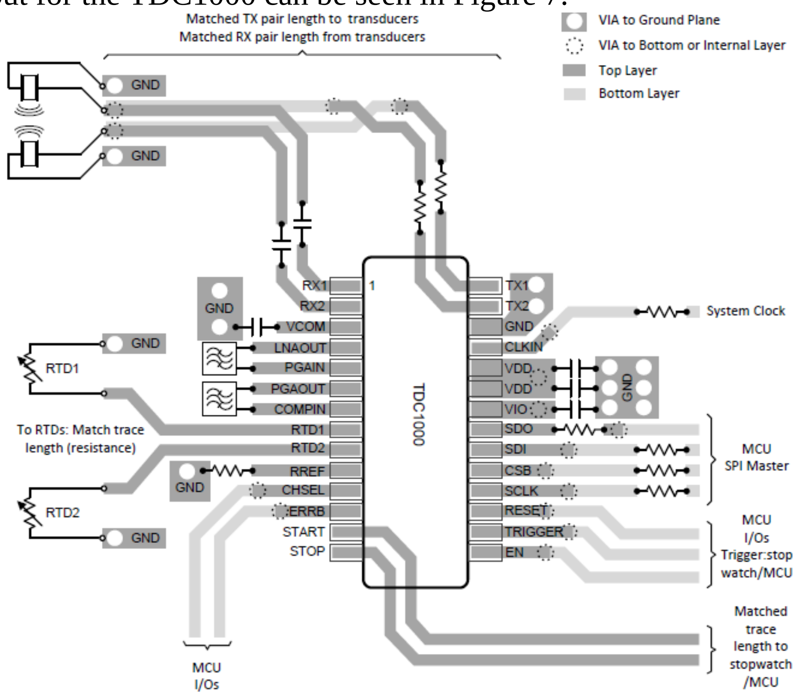

Figure 7 - TDC1000 Example Layout

High Voltage Driver

A typical sensor excitation voltage is 5V. However, for applications with deeper tanks, we recommend exciting the sensor with a higher voltage. This ensures that the reflected wave will not be lost if the tank is shaky or if the fluid is unstable. One example for this scenario is a urea tank in a diesel-engine car.

In this design, we chose to boost the 5V 50% duty cycle pulse wave to 30V to excite the sensor. Since the TDC1000 has dual channels, only one channel will have the boost while the other channel does not. This is aligned with most applications where one sensor is used to detect fluid level, while the other sensor is used to identify the fluid or its concentration, and thus, high voltage is not necessary. This design uses RX2 and TX1 as the channel for the boost.

The boost converter to step up 5V to 30V is the TPS61170-Q1 (Figure 8). The advantages of this IC includes automotive qualification, requires less external components, and draws very little current.

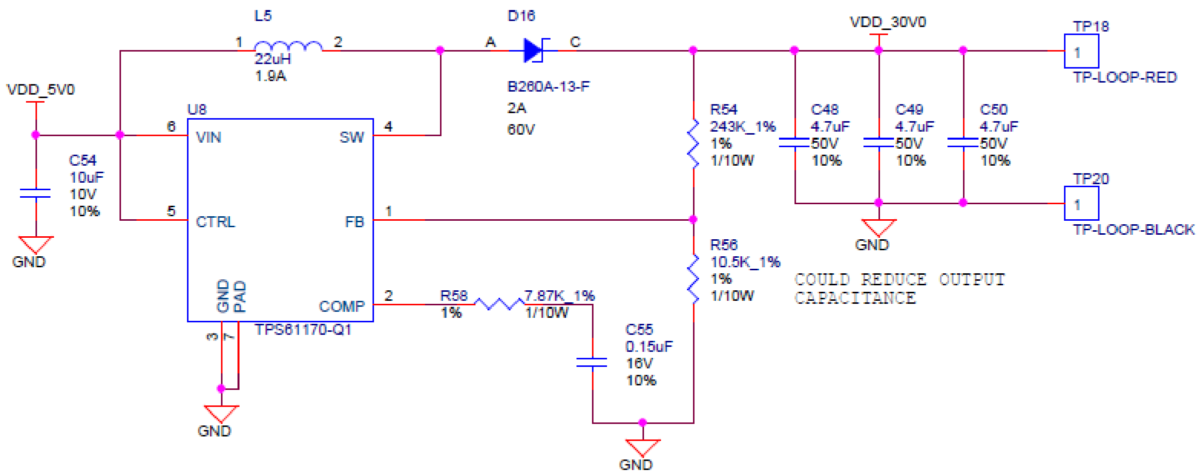

Figure 8 - Boost Converter Circuit

The second important device for this circuit is the driver IC UCC27531-Q1. Its main purpose is to create a 50% duty cycle 30V square wave pulses to excite the transducer. There is one main reason why we used a driver IC instead of a simple circuit consisting of transistors to step up the transmit pulses. The driver ICs offer integrated shoot-through protection, which is needed because shoot-through has two consequences:

a. It drains the output caps of the boost converter quickly. We would need a boost converter with much more power to compensate for these losses.
b. It could simply thermally destroy the transistor stage.

The UCC27531-Q1 can be disconnected from the positive supply rail in order to get a high impedance output. This is done by driving the HV_PWR_EN high. It is important to place the driver in high impedance output to attenuate the ultrasonic echo less, and therefore, increases the signal strength. Echo voltages of around 1V pk-pk could be measured for a measurement distance of 5' (approx. 1.5m).

One of the problems with the UCC27531 is its turn-on time. It is important that the driver IC turn on before the MCU inserts a TRIGGER pulse for the TDC1000 to start the transmit pulses. The turn-on time, of the UCC, therefore, needs to be fast, and this is done by increasing the PFET's (Q1) Miller plateau. To achieve this requirement, place a 220pF capacitor between the gate and drain of the PFET that controls the VDD, and add a resistor R23 of 51kΩ, as seen in Figure 9. This method increases the length of the PFET's Miller plateau, which therefore leads to the UCC turning on before the TX fires.

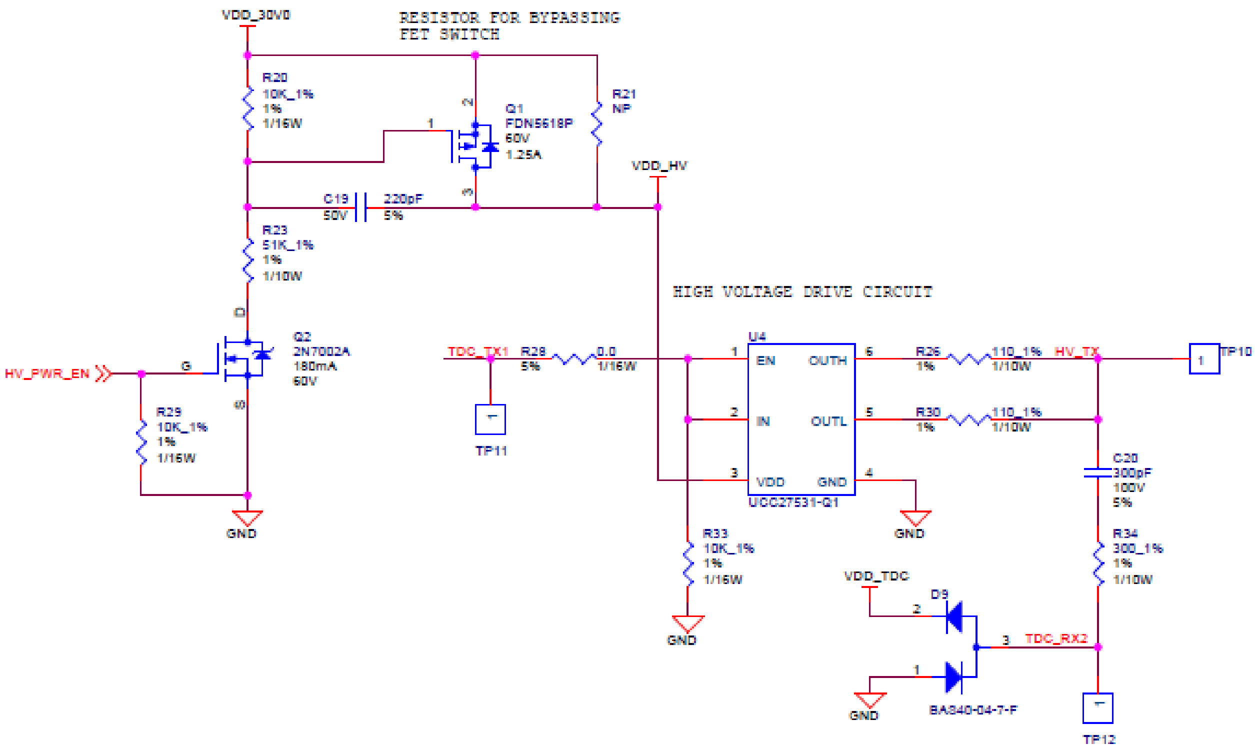

Figure 9 - Driver Circuit

MCU

The TMS320F28035-Q is the on-board microcontroller that captures all the time-of-flight (ToF) data from the TDC1000 ultrasonic AFE and converts it to a digital code. The ToF is defined as the difference between the START and STOP pulses, which is done by the MCU using the OR circuit seen in Figure 10.

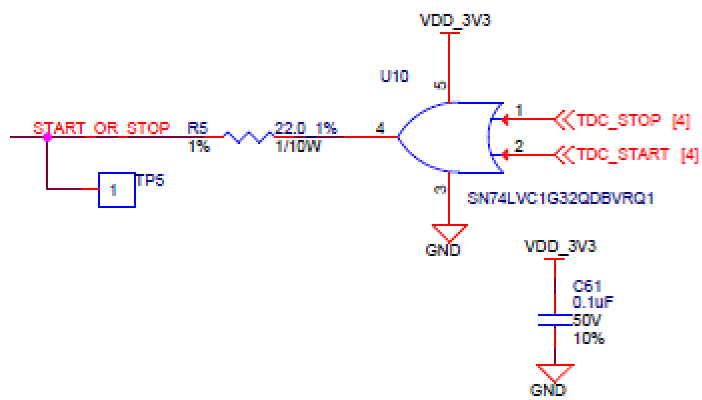

Figure 10 - START/STOP circuit to MCU

There are two major reasons why the TMS320F28035-Q is picked for this automotive reference design: the MCU is an automotive qualified device, and it has 300ps accuracy, which is ideal for fluid level, identification, and concentration applications.

The TMS320F28035-Q also handles all the serial peripheral interface to-and-from the Ultrasonic AFE, and the UART communication to talk to the GUI software.

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