TEXAS INSTRUMENTS

Application Report

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Ultrasonic Sensing for Fluid Identification and Contamination

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ABSTRACT

Ultrasonic sensing utilizing Time Of Flight (TOF) measurement techniques can be used to monitor material purity/contamination levels and or to differentiate materials non-invasively. This technology has been utilized in the automotive, consumer, medical and food preparation markets worldwide. Ultrasonic (TOF) sensing can yield high accuracy with low power consumption for all of these markets. This Application Note will demonstrate such measurements utilizing TI's TDC1000 Ultrasonic Analog Front End and an inexpensive "test cell" for a variety of automotive fluids.

Topic **Page**

1 Overview

In a homogeneous material (gas, liquid or solid), the speed of sound is well characterized. Having access to this information enables someone to use ultrasonic sensing to identify a particular material from a group of potential materials or at the least identify that a material is not from a select group. For instance, in the automotive industry, there are several liquids that could be monitored in their respective reservoirs for the purpose of alerting a driver to take action before potential engine damage occurs or a dangerous circumstance arises. Examples of these fluids are windshield washer fluid, engine coolant, and engine oil.

1. **Windshield Washer Fluid**: In climates where temperatures vary greatly over the course of the year, different washer fluid is used in the winter that is not needed in the summer. In the winter, it is critical that drivers use wiper fluid with antifreeze. It is easy to imagine a situation while driving in freezing weather conditions where incorrect wiper fluid (version with little or no antifreeze) is present in the wiper fluid reservoir. In this circumstance, the normal activity of pushing the wiper fluid button in order to clear ice from the windshield will be ineffective as a result of the fluid in the reservoir having turned slushy or completely into a solid. A simple ultrasonic “concentration” sensor that monitors anti-freeze levels in wiper fluid could be built into the tank and prevent the surprise of having frozen wiper fluid or the absence of sufficient wiper fluid for normal operation.

Table 1. Freezing Point of Propanol-Based Water Solutions

	FREEZING POINT										
Propanol Concentration (% by volume)	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Temperature (°F)	32	25	20	5	0	-5	-10	-20	-35	-70	-130
Temperature (°C)	0	-4	-7	-15	-18	-21	-23	-29	-37	-57	-90

2. The same situation could be true for engine coolant. If the antifreeze (ethylene glycol) level were to drop too low, the engine block could freeze and crack causing major engine damage.
3. Another diagnostic capability for ultrasonic fluid identification would be monitoring the quality or contamination levels of engine oil.

2 Approach

As mentioned in the abstract, the ultrasonic TOF measurement technique described in this application note will utilize TI's TDC1000-C2000EVM and an inexpensive test cell. To purchase or obtain details on the EVM, please go to http://www.ti.com/tool/tdc1000-c2000evm. The test cell is comprised of a 1" by 1" by 2" acrylic container with a 1 Mhz transducer mounted externally. See application note SNAA266 for details on how to mount transducers on a tank.

The material speed of sound measurements will be based on the following block diagram shown in Figure 1:

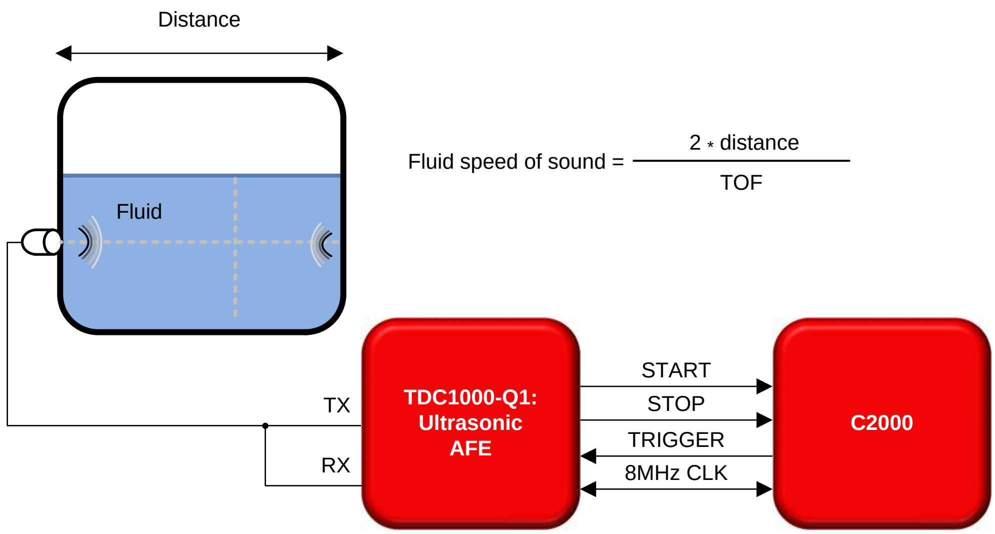

Figure 1. Fluid Identification Block Diagram

Figure 2 shows the test cell with mounted transducer:

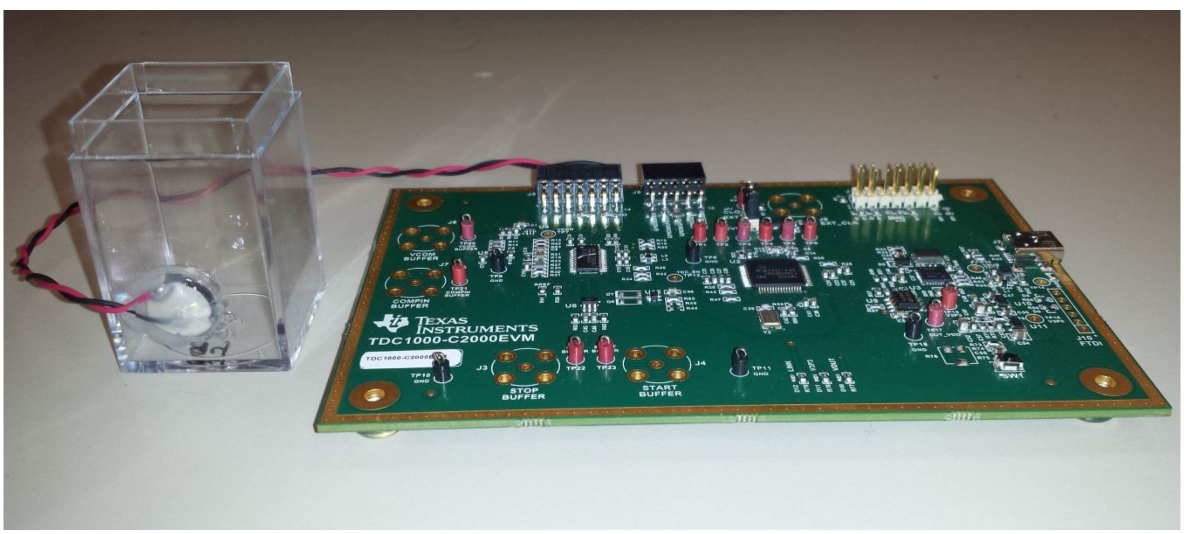

Figure 2. TDC1000-C2000 EVM with Test Cell

Speed of sound varies over temperature, so the measurements done below will be performed on fluids at the same temperatures. More specifically, the temperature will be controlled via the water bath method where all of the samples will remain in a water filled vessel for one hour, allowing the fluids to thermally stabilize. In order to avoid any error due to differences in the physical dimensions of the test cell, the same test cell is used to measure the different fluids.

3 Measurements

The three tables below contain the TOF measurement results for the 3 different automotive liquids. The goal of this exercise is not to determine the absolute speed of sound values for the tested solutions. It is to demonstrate an easy way to identify the fluid or more importantly, to identify that the fluid is exhibiting properties outside of the normal expected ranges and thus the driver should take action to address the problem.

Table 2. Wiper Fluid

Wiper Washer Fluid	TOF(ns)	Delta T (ns) (comparing to closest dilution)
Wiper fluid	38956.56	
Wiper fluid with 40% alcohol	39089.11	-132.55
Wiper fluid with 70% alcohol	42094.35	-3005.24
Wiper fluid with 80% alcohol	44481.5	-2387.15

Table 3. Engine Oil

Engine Oil	TOF(ns)	Delta T (ns) (comparing all to Manufacturer X_5W30)
ManufacturerX 5W30	40453.08	
ManufacturerX 5W30 after 10k miles use	40299.49	153.59
ManufacturerY 5W30	40419.56	33.52
ManufacturerX 10W40	40127.51	325.57

Table 4. Engine Coolant Dilutions

Engine Antifreeze	TOF(ns)	Delta T (ns) (comparing to closest dilution)
Coolant with 50% dilution	35462.63	
Coolant with 60% dilution	36007.78	-545.15
Coolant with 70% dilution	36711.92	-704.14
Coolant with 80% dilution	37617	-905.08
Coolant with 100% dilution	39907.86	-1207.28

Measurement Summary

After close review of the data collected on the three fluid samples, the delta time of flight numbers indicate what timing measurement accuracy each application requires. For example a 20 Mhz (+/-50 ns) microprocessor based counter could easily provide the timing resolutions (100's of ns) required to resolve the material samples for the wiper fluid and antifreeze. While a better than 10 ns time resolution measurement would be required for the engine oil measurements. For time measurements less than 10ns, counter based timers can be an issue as they require clock frequencies greater than 100Mhz. For those applications where a high resolution timer capability is not practical or available in the microprocessor, a general purpose "stopwatch device" such as the TDC7200 can be utilized as it can resolve below 1ns for time scales from nanoseconds to milliseconds. Fluid identification via ultrasonic TOF measurement techniques utilizing the TDC1000 Ultrasonic Analog Front End and a C2000 based processor with an internal TDC function is possible for the three automotive fluid samples measured.

4 Conclusion

As shown in this application note, ultrasonic sensing utilizing Time Of Flight (TOF) measurement techniques can be used to monitor material purity/contamination levels and or to differentiate materials non-invasively. While this application note focused on automotive fluids, the technique of using ultrasonic sensing to identify different fluids or detect changes in a given fluid's density due to the presence of impurities is applicable across the industrial and consumer markets as well. In general, the high accuracy, low power consumption, and low system cost makes Ultrasonic (TOF) sensing a viable solution for many applications.

For more details on TI's Ultrasonic Sensing solutions and supporting collateral, please go to http://www.ti.com/ultrasonic.

5 Footnotes

1. http://www.engineeringtoolbox.com/ispropanol-water-d_988.html

Revision History

DATE	REVISION	NOTES
April 2015	*	Initial release.

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