TDC1000-Q1 in Automotive Ultrasonic Level Sensing Systems

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As the demand for tank level sensing precision increases within the automotive market, more accurate solutions oftentimes replace the existing mechanical ones. Furthermore, the demand for liquid level measurements in additional fluids poses another substantial obstacle to hurdle, as fluid properties and tank conditions play a substantial role in influencing sensor technology choice. Due to these primary factors pushing for disruptive innovation, the affordable, accurate alternative of ultrasonic level sensing in the automotive domain presents an appealing solution.

Automotive Ultrasonic Level Sensing

Traditional level sensing systems usually involve mechanical solutions incorporating magnetic floats, potentiometers, and reed switches. However, as the need for accuracy increases, mechanical solutions are becoming more and more obsolete. Instead, solutions leveraging time of flight (TOF) technology grow in popularity. This is due to the fact that many of the present day microcontrollers possess the timing accuracies necessary to measure fluid level with resolutions on the order of millimeters, if not micrometers. This provides the information necessary for proper fluid maintenance.

The other primary advantage to ultrasonic level sensing involves fluid properties. Take diesel exhaust fluid, for example. Diesel exhaust fluid's corrosiveness limits the ability to use any mechanical float type solutions or any other systems involving contact. In contrast, an external, nonintrusive system serves as a viable solution due to its avoidance of contact with the corrosive fluid. Another important example deals with fluid viscosity. Viscous fluids such as engine oil or brake fluid leave films on the tank and any internal devices, causing problems for the popular capacitive sensing solutions. However, ultrasonic level sensing is an external, nonintrusive system. This implies that the fluid properties aforementioned pose no threat to system performance. These two examples also illustrate the necessity to consider all fluid properties before making the decision on level sensing technology, as foamy fluids, for example, can even cause problems for the seemingly infallible ultrasonic sensing solutions. Table 1 summarizes a few more common key property considerations.

Once the decision to use ultrasonic level sensing has been made, a basic understanding of the technology must exist in order to succeed in designing an optimal solution. At its core, ultrasonic level sensing incorporates TOF measurements to deduce either the distance, leveraging a known velocity, or the velocity, leveraging a known distance. Level sensing employs the former. Figure 1 displays the application visually. Treat "Target" as fluid boundary.

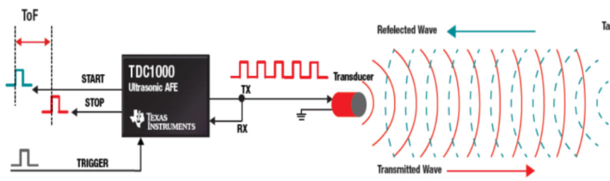

Figure 1. TDC1000 Application Diagram

The TOF (difference between START and STOP signal) can be used to calculate the distance between the transducer and fluid boundary through the equation $d=v*t/2$. Note: v is the speed of sound and t is the TOF measured. The division by two is necessary due to the fact that the wave travels to and from the fluid boundary.

Concentration sensing serves as a perfect example of the latter of the two options aforementioned, i.e. ultrasonic concentration sensing leverages a fixed distance to deduce substance or impurity concentration. Since the speed of sound will vary based on fluid concentration, programmed look up tables of speed of sound vs. fluid concentration can be used to accomplish this. Furthermore, any deviations from the expected concentration can be identified based on the change in TOF, and provided that the aberrations exceed set tolerance thresholds, the appropriate signals can be sent to maintain fluid integrity. The necessary formula to calculate the speed to look up is $v = 2d/t$.

With those basics in mind, it is also important to understand the fluids present in vehicles and the potential opportunities for ultrasonic sensing. The following list breaks down many fluids, other than fuel, essential to passenger vehicle performance:

- Hydraulic Fluids
  - Brake Fluid
  - Power Steering Fluid
- Lubricants
  - Engine Oil
  - Gear Oil
  - Differential Oil
- Coolants
  - Engine Coolant
  - AC Coolant
- Windshield Washer Fluid
- Other Fluids
  - Diesel Exhaust Fluid
  - Water and/or Methanol

From these fluids, engine oil, diesel exhaust fluid, and fuel are the three prime opportunities for ultrasonic level sensing. Beyond those, engine coolant and the hydraulic fluids seem to hold the most opportunistic value, as an inadequate amount of either could pose serious safety hazards. The good news for automotive ultrasonic level sensing is that ultrasonic technology can handle each of those fluid opportunities.

TDC1000-Q1: An Integrated AFE

The job of an analog front end (AFE) in the ultrasonic domain consists of a few primary, high level tasks. First and foremost, it must have the ability to drive the transducer. Furthermore, once the transmitted wave leaves the transducer, the AFE must be able to identify, based on a specified threshold, when the transmitted wave has come back in order to properly receive it, ignoring any noise, and take the necessary following steps. Concurrently, the AFE should send a START signal to the MCU once the transducer has been driven and send a STOP signal once the wave has reflected and traveled back to the transducer. Finally, it should have an input channel, providing a pathway for the MCU to send a TRIGGER signal to restart the entire process. Figure 2 shows the TDC1000-Q1 block diagram.

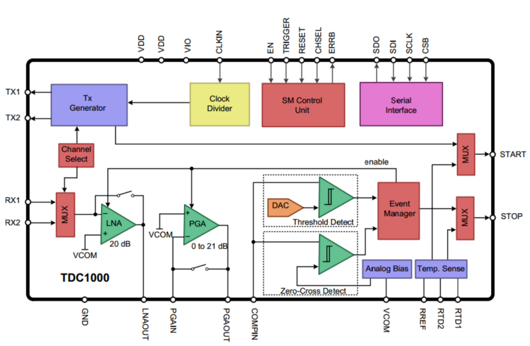

Figure 2. TDC1000-Q1 Block Diagram

Notice that the TDC1000-Q1 has two transmit and receive channels. This plays an essential part in allowing for two simultaneous measurements to be taken. For example, with diesel exhaust fluid, it is important to ensure the level and concentration meet safety and environmental standards. The TDC1000-Q1 can help accomplish both. Figure 3 displays a block diagram accomplishing just that. Side note: The TDC1011-Q1 has a single channel, so if only one measurement is needed, then the TDC1011-Q1 is the cheaper option.

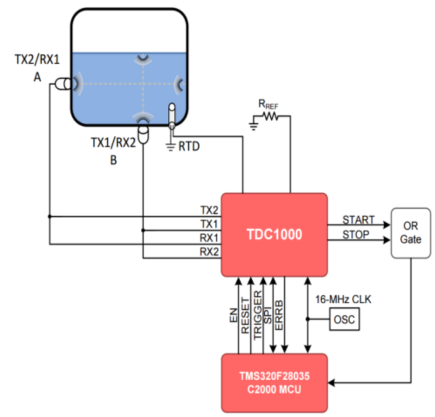

Figure 3. Level and Concentration Sensing

The question arises, why use an integrated AFE vs. a discrete multi-amplifier stage? The primary reason remains that the mechanical form factor specified by OEMs creates difficulty for tier 1 suppliers in regards to solution size. Therefore, an integrated device such as the TDC1000-Q1 helps tier 1 companies meet the OEM specified dimensions.

1 - Size

Integration is becoming a necessity as mechanical constraints pose more and more issues. The TDC10xx-Q1 parts are the only automotive qualified ultrasonic AFEs on the market. As a completely integrated analog front end, the TDC1000-Q1 remains one of very few options if a reduction in size is required. TDC1000-Q1's package is 9.7 x 4.4 mm, TSSOP.

2 - Cost

Integration can also prove to be a worthwhile contributor in lowering overall system and component cost. Furthermore, constructing a system with the TDC1000-Q1 implies a future reduction in overall design and testing costs since the TDC1000-Q1 can be reprogrammed to fit the new system.

3 - Adaptability

Every vehicle is different, and each vehicle contains multiple tanks, all of different shapes and sizes. As the number of accurately measured automotive fluids increases, a more flexible solution will soon be necessary. The TDC1000-Q1 can work in a variety of tank conditions. Its programmability provides flexibility, which allows for scaling the solution across multiple level sensing platforms. In summary, leveraging the programmability of the TDC1000-Q1 allows engineers to have a set hardware BOM (bill of materials) across multiple different designs.

Additional Resources

- Order the TDC1000-C2000EVM (For Level and Concentration).
- View the Automotive Ultrasonic Fluid Level/Quality Measurement Reference Design.
- Download the TDC1000 Datasheet.
- Download the TDC1000-C2000EVM User's Guide.

Table 1. Additional Technologies and Properties

	Solids	Clear	Opaque	Foamy
Laser	Yes	No	Yes	Material Depend.
Microwave	No	Yes	Yes	Yes
Ultrasonic	Yes	Yes	Yes	No
Pressure	No	Yes	Yes	No
Capacitance	Mat. Dep.	Yes	Yes	No