

How to Select and Mount Transducers in Ultrasonic Sensing for Level Sensing and Fluid ID

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ABSTRACT

Ultrasonic sensing utilizing Time Of Flight (TOF) measurement techniques are used in liquid level and fluid identification sensing in the automotive, consumer and medical markets. Ultrasonic (TOF) sensing can yield high accuracy and high reliability with low-power consumption for all of these markets. In order to achieve the best cost-to-performance combination, care must be taken in selecting the proper transducer. Cost-sensitive applications can be serviced by utilizing bare (unsealed) transducers making measurements directly through container walls. This application note discusses how to select the most appropriate transducer for liquid level sensing and fluid identification applications. In addition to sensor selection, proper techniques for mounting transducers on the outside of tanks for rapid prototyping is also addressed in this application note.

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Trademarks

1 Transducer Selection

Selecting the right transducer starts with understanding what and how you want to make your level sensing or fluid identification measurement. TI's TDC1000 handles ultrasonic TOF measurements and can work with transducers that have a resonance frequency from 30 KHz to 4 MHz. When choosing a transducer, the following questions need to be answered: What frequency? What size? Which Piezo material? Where does it need to be mounted? What temperature range? Each of these questions will be discussed in more detail below.

1.1 What Frequency?

The frequency you choose depends on your application. Every transducer will resonate at multiple frequencies depending on its piezoelectric material composition and its geometry. A deep discussion of this topic is not within the scope of this document. As such, this application note only discusses transducers of the disc variety working in axial or thickness mode.

1. The frequency of your transducer and the transmit pulse length can determine axial (depth) resolution. The higher the frequency, the tighter the resolution [1]. In general a 1 MHz transducer yields better than 1 mm resolution in most liquid level sensing applications. Proximity sensing applications on the other hand use 40 kHz transducers, while gas flow meters use 200 kHz transducers. In general, propagating an ultrasonic wave through liquids allows system designers to use transducers in the MHz range while applications where the ultrasonic wave will propagate through a gas require transducers anywhere from 40 kHz to 500 kHz depending on the distance the wave needs to travel and the accuracy requirement of the measurement.

$$\text{Axial resolution} = (\lambda * \# \text{ cycles})/2 \quad (1)$$

2. The higher the transducer frequency, the tighter the beam width [2,3].
3. The smaller the transducer diameter, the wider the beam width [2,3].

$$\text{Sine}(\theta) = 1.2 * V/(DF) \quad (2)$$

where:

- θ = Beam divergence angle
- V = Sound Velocity in the material (m/sec)
- D = diameter of transducer (m)
- F = Frequency of transducer (Hz)

1.2 What Size?

1. The smaller the transducer diameter, the less efficient the transducer is at creating an ultrasound pulse. In addition, smaller diameters make the transducer less sensitive while trying to detect a pulse. So in general, larger transducers improve signal to noise ratio at the expense of surface area on a container wall and cost.
2. The size of a transducer is also influenced by its material composition.

1.3 Which Piezo Material?

There are several different materials offered by piezo manufactures and each have their tradeoffs. In general, they differ in sensitivity (ability to convert voltage into mechanical displacement). Here is a list of the most common materials.

1. Barium titanate (older technology)
2. Lead zirconate titanate or PZT is most commonly used today. For more information, the following is a good website for information on the different types of PZTs: <http://www.bjultrasonic.com/ultrasonic-technical-info/piezoelectric-ceramic-technical/>

It is common for a piezo manufacturer to not include information about material in their datasheets. If that is the case, it is recommended to ask the manufacturer in order to make sure that the performance would be similar to the PZT sensors that are recommended in application notes SNIA020 (Water Flow Meter) and SNAA265 (Fluid Identification and Contamination).

1.4 1 MHz Transducers for Liquid Level Sensing and Fluid Identification

For the scope of this Application Note, 1 MHz transducers will be the primary focus. In the table below are the transducers that have been tested with the TDC1000 for level sensing and liquid identification. All of the transducers are approximately 2 mm thick. This is due to the requirement of axial (thickness) resonance mode of 1 MHz for these applications. Some of these are listed on their websites referencing their radial resonance frequencies. It's important to understand they are both correct and that care needs to be taken when selecting a transducer.

Table 1. Tested Transducers

| FREQ (THICKNESS MODE) | THICKNESS (mm) | RADIUS (mm) | SEALED | MODEL # | VENDOR WEBSITE |
|-----------------------|----------------|-------------|--------|----------------------|---|
| 1 MHz | 2 | 10 | N | SMD10T2R111WL | https://www.steminc.com/PZT/en/piezo-ceramic-disc-10x2mm-r-215-khz-wire-leads-smd10t2r111wl |
| 1 MHz | 2 | 15 | N | SMD15T21R111WL | https://www.steminc.com/PZT/en/piezo-ceramic-disc-1-mhz |
| 1 MHz | 2 | 7 | N | BSU-P7-1000B-W200 | http://www.bestartech.com/piezo-element-dia.-thickness-p-435-l-en.html |
| 1 MHz | 2 | 10 | N | BSU-P10-1000B-W200 | http://www.bestartech.com/piezo-element-dia.-thickness-p-436-l-en.html |
| 1 MHz | 2 | 15 | N | BSU-P15-1000B-W200 | http://www.bestartech.com/piezo-element-dia.-14.85-thickness-p-437-l-en.html |
| 1 MHz | 2 | 15 | N | AW5Y15.5200AL145 | http://www.audiowell.com/en/product-detail.aspx?id=53 |
| 1 MHz | 2 | 15 | Y | T/R975-US0014L353-01 | http://www.audiowell.com/en/product-detail.aspx?id=58 |
| 1 MHz | 2 | 14 | N | AW5Y14200A | http://www.audiowell.com/en/product-detail.aspx?id=54 |

2 Tank Wall Transducer Mounting

2.1 Where Does the Transducer Get Mounted?

1. Inside or outside the tank? Inside or outside the tank will greatly affect the cost of the transducer. Applications that require transducers to be mounted on the inside of a tank need sealed transducers that are mechanically more complex as they need to withstand chemical (liquid) exposure. On the other hand, applications that allow transducers to be mounted on the outside of a container can utilize bare, unsealed transducers which are much lower cost. These applications also have the added benefit of being non-invasive and can be retrofitted to existing tanks. In general, if an application can tolerate external mounting, total system cost is reduced and the system benefits from higher reliability and accuracy.
2. Top or bottom of the tank? Top or bottom will also greatly affect the cost of the transducer and the resonance frequency. If the transducer is mounted on the bottom of the tank on the outer wall, the bare transducer type can be utilized. However, if the transducer is mounted on the top in the inner wall, for example to measure level, the conducting medium for the ultrasonic wave is now a gas, and thus the resonance frequency of choice needs to be 40 kHz to 200 kHz depending on the level accuracy requirement and level height that is being monitored. For fluid identification applications, transducers are typically mounted on the outside of the outer wall. Since the transducers will not come in contact with the liquid medium inside the container, the less expensive, bare transducers can be utilized.
3. Temperature range? Most PZT should not be used above 80°C as it degrades the piezoelectric capability rendering it ineffective. For high temperature applications, appropriate transducers are available such as Modified lead metaniobate which is available from the following vendors: <http://www.trstechnologies.com/Materials/High-Temperature-Piezoelectric-Ceramics> and <http://www.piezotechnologies.com/piezoceramics>

2.2 Transmitting Through a Tank Wall

It is possible to transmit through most tank walls because the ultrasonic waves travel through tank walls with no issues depending on the measurement requirements and mounting techniques. Soft tank materials, such as automotive HDPE (High Density Polyethylene) and Stainless Steel, have been tested with good results. The process has two key features to maximize success:

1. Good mechanical connection between the transducer and the tank wall. This is achieved using Cyanoacrylate adhesive as it cures quickly with low compressibility and high adhesion to most materials.
2. Transducer backside acoustic dampening (and wire strain relief). This is achieved using “Hot glue” as it has high adhesion to acrylic and moderate flexibility allowing for both acoustic dampening and good wire strain relief. Commonly available silicon RTV can be used instead but requires a longer (24 hr) cure time.
3. The tank wall is homogeneous (has no air gaps and/or is not porous in nature). Air gaps cause reflections and can attenuate the ultrasonic waves, thus prohibiting them from passing through the wall.

2.3 Assembly Steps

1. Roughen 1 cm square area on lower side of plastic container with sandpaper.

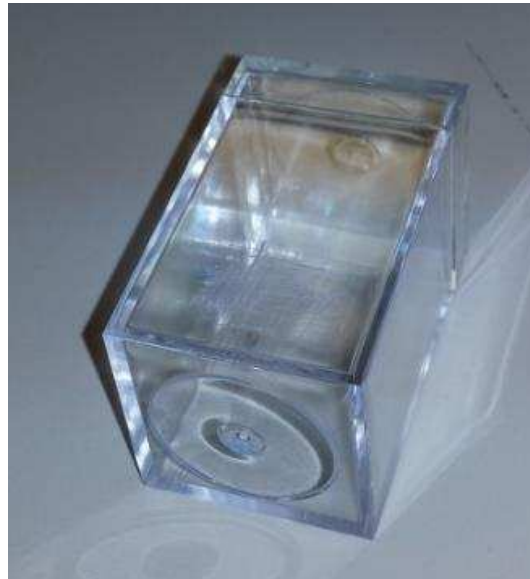


Figure 1. Test Container Preparation

2. De-grease with alcohol.
3. Dry area with air gun.
4. Apply CYA glue to 1 cm square area.



Figure 2. Applying CYA to Test Container

5. Attach transducer to glue spot with leads out to side of container.

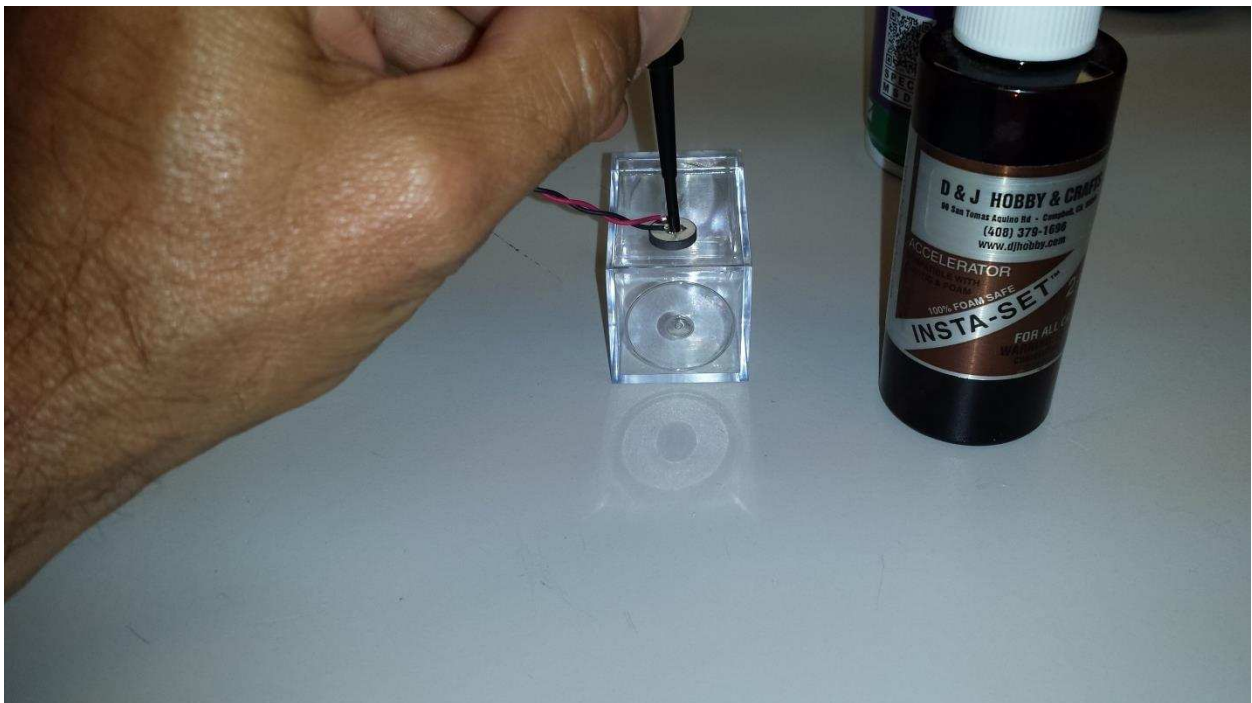


Figure 3. Mounting Transducer to Test Container

6. While applying gentle pressure to transducer to hold it in place apply “CYA Accelerator” to transducer.
7. Wait approximately 15 sec for glue to cure. Blow off excess Accelerator.
8. Apply alcohol to clean area. Dry area with air gun.
9. Apply hot glue around the circumference of the transducer.



Figure 4. Applying Hot Glue to Transducer

10. Continue covering transducer until it is completely covered in hot glue.
11. Use air to gently cool glue.

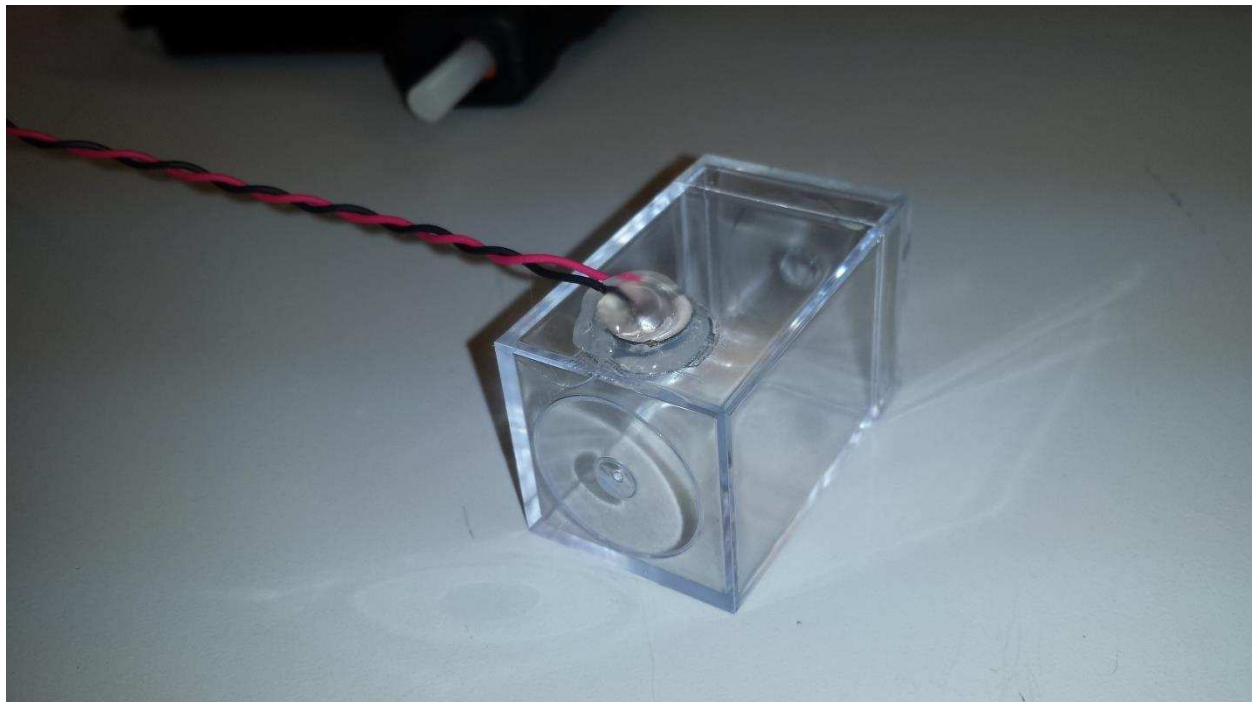


Figure 5. Completed Assembly

3 Required Supplies

- **CYA Glue with Latex**

This CYA has latex in it which makes it a good compromise for incompressibility (CYA) and flexibility (latex) to ensure the transducer will not shear off the flexible tank wall.

- **CYA Accelerator**

Both of the above are from this vendor which is available on amazon.com: <http://www.bsi-inc.com/Pages/hobby/ca.html>

- Plastic "test cell" container
- 400 grit sandpaper
- Alcohol
- Hot glue gun
- Ultrasonic transducers w/attached wires
- Spray duster/ air gun

4 Tank design modifications to accommodate transducer

The previous section discussed the process of mounting a transducer externally to a tank for prototyping purposes. This section discusses some considerations to take into account when modifying a tank to accommodate an unsealed transducer. The tank design modification consists of creating a receptacle or mounting "well" where the transducer can be protected from external damage and allow for acoustic dampening material to increase short range performance. Below are some mechanical drawings to consider when modifying a tank design. For the following discussion I'll be utilizing a 2.1mm thick transducer. The adhesive considerations are the same as discussed in the above sections.

The first consideration is to leave enough space radially around the transducer to prevent radial vibrations from propagating into the tank wall in the direction opposite from what's required for a level measurement. As is shown below a 2mm clearance should easily achieve this and allow an acoustic dampening material (in this case RTV silicone) to enter the gap and help dissipate radial vibrations. The next consideration is to recess the transducer into the tank wall deeply enough to allow for a minimum of 1x the transducer thickness of acoustic dampening material (RTV etc.). For the example below the transducer receptacle is depressed approximately 4.1mm in from the tank's outer wall. Deeper recession may help reduce the transducer ring-down depending on the dampening material and tank construction.

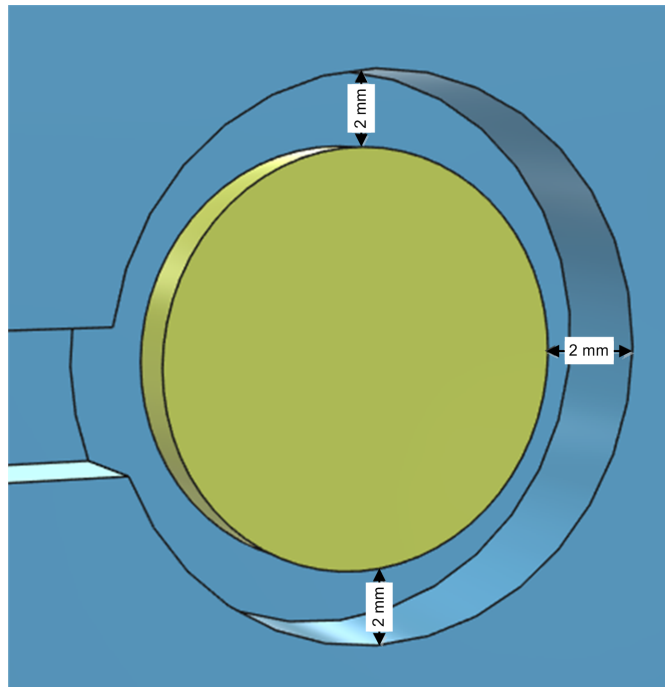


Figure 6. Transducer Receptacle Clearance (Front View)

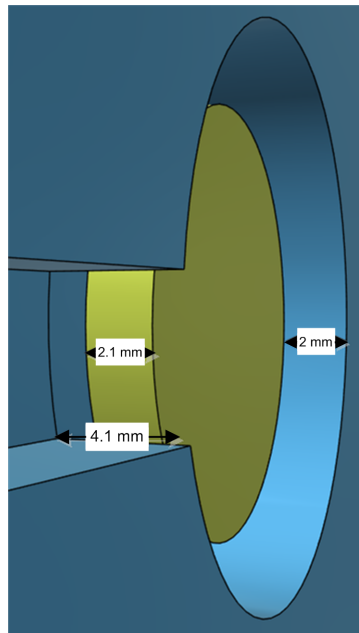


Figure 7. Transducer Receptacle Clearance (Side View)

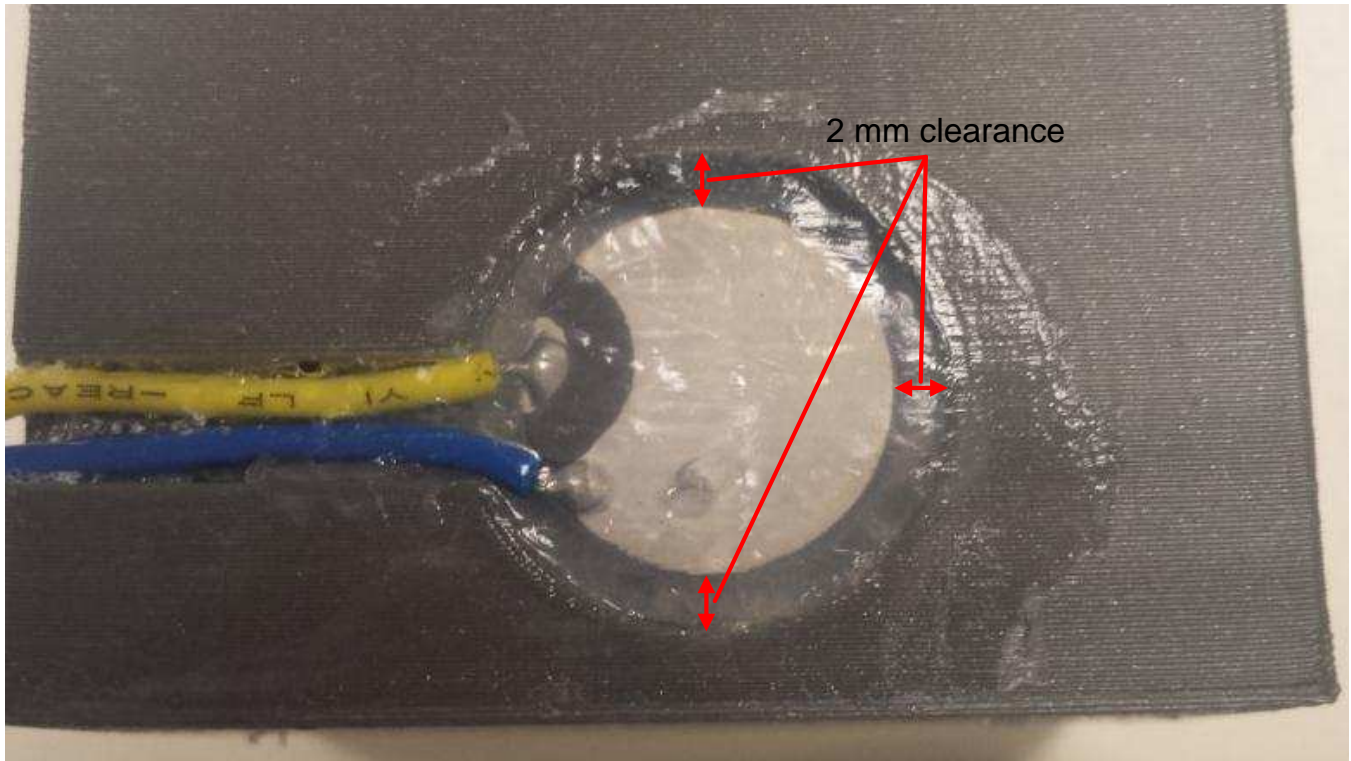


Figure 8. Transducer Receptacle (Top View)

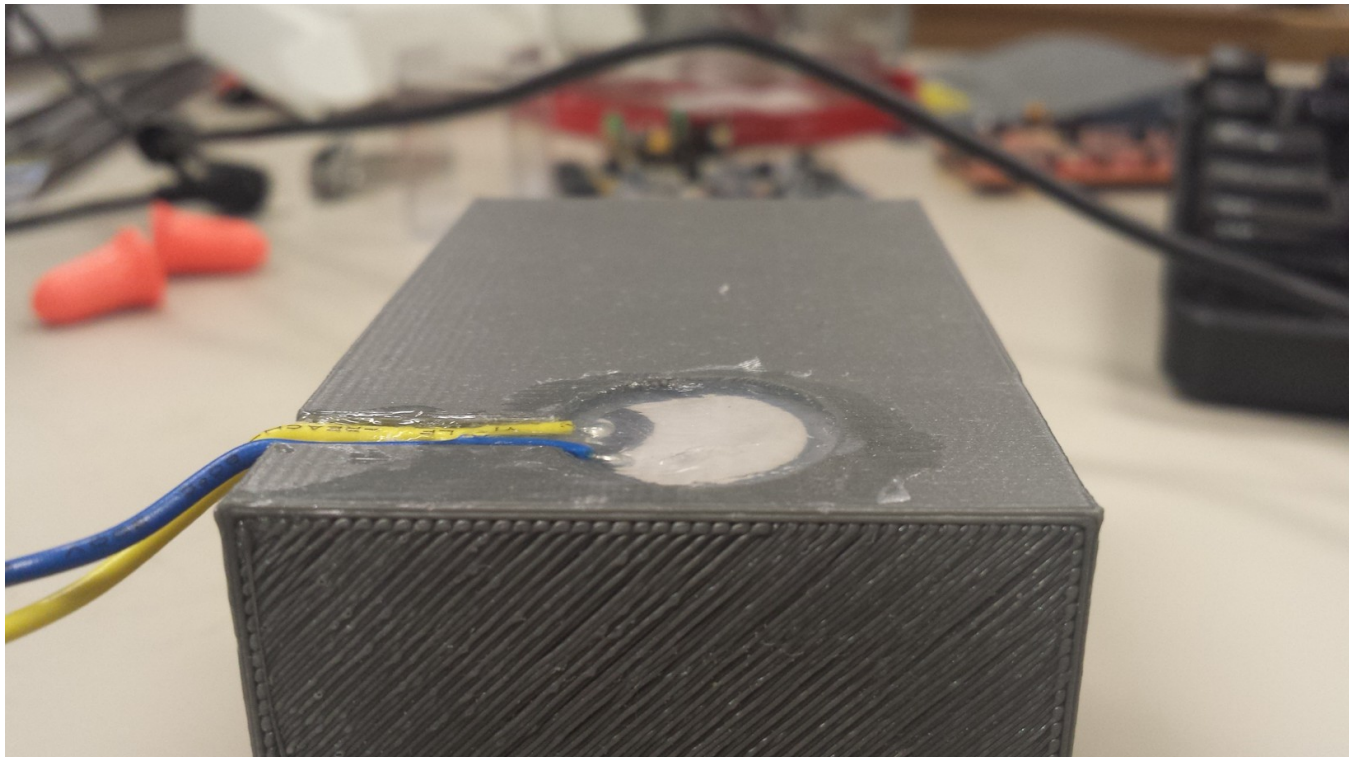


Figure 9. Transducer Receptacle (Side View)

5 Conclusion

Ultrasonic sensing utilizing Time Of Flight (TOF) measurement techniques is used in liquid level and fluid identification sensing applications. In order to create a solution that is optimized for size, cost, and performance, one must first choose the right transducer for the application. Determining if the application can tolerate the transducer being mounted on the outside of the tank is the first start. Once this is known, a system designer can select a transducer with the appropriate package requirements and resonance frequency. With the transducer selected, the designer can now start to prepare the tank surface for proper transducer mounting. Having properly mounted the transducer, Texas Instruments TDC1000 can be connected to the transducer and application specific measurements can begin.

Texas Instruments offers a wide variety of tools in order to help a system designer create their ultrasonic sensing solution for liquid level sensing, liquid identification, and flow sensing using the TDC1000. Visit <http://www.ti.com/ultrasonic> for more details on the tools and collateral available.

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