Acu-Trac® Ultrasonic Performance Considerations

Product Overview

An understanding of the variables that affect the performance of an ultrasonic distance sensor application is important to maximize reliability. The following discussion covers the major influences that can affect the overall performance of an ultrasonic distance measurement system. For discussion purposes these variables have been categorized as follows:

- Temperature
- Target Composition, Location and Motion
- Ultrasonic Sense Element Characteristics
- Transmission Media
- Acoustic Noise

Temperature Considerations

The speed of sound is inversely proportional to temperature as can be seen in the following mathematical relationship:

$$V = 331 \times (1 + T/273)^{\frac{1}{2}} \text{ m/sec}$$

The implication for distance sensing is that to create an accurate measurement the distance sensor must monitor the ambient temperature and then compensate for the change in the speed of sound. All of SSI's ultrasonic distance sensors perform the temperature compensation with each distance reading to maintain accuracy.

Temperature also affects the distance sensors electromechanical components and in particular the performance of the ultrasonic sense element. SSI's Acu-Trac® system manages the changes to optimize the sense elements performance for temperatures within the distance sensors operating region, -40 °C to 85 °C. Temperature excursions beyond this range can be detrimental to the distance sensor and cause irreversible damage to the ultrasonic sense element. SSI's ultrasonic distance sensor design forces a default for temperatures outside of the specified operating range to minimize any potential damage to the sense element. From an application standpoint, it is important to limit the ambient temperature to a maximum of 85 °C.

Target Location, Composition, and Motion

In order for a sound wave to reflect off a target there must be a marked density difference between the target and the media in which the sound is traveling through. If the target absorbs a significant portion of the transmitted sound energy then the reflected echo's amplitude will be greatly diminished reducing the distance sensor's maximum operating range. For example, sound waves reflect easily off dense targets such as liquids, aggregate, cardboard, wood and metallic. However, sound waves are absorbed by porous targets such as open cell foam and certain types of powders, which make poor candidates for an ultrasonic measurement application.

Sound energy is also absorbed by humidity, as can be seen in figure 1. The implications for the system designer are that the distance sensor must be specified with sufficient operating margin to overcome the losses caused by humidity changes.

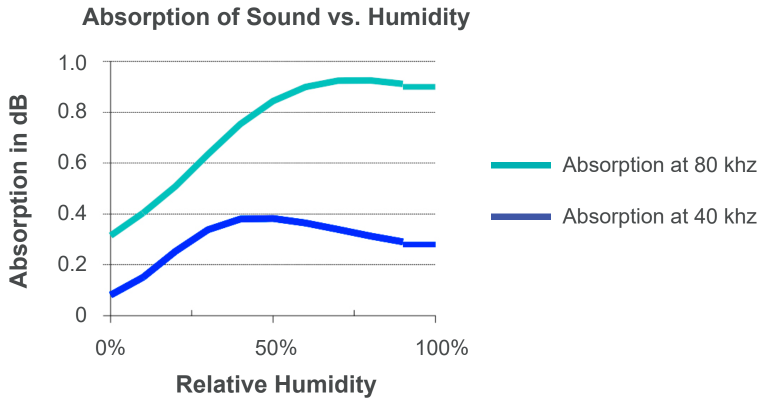


Figure 1: Absorption of Sound Verses Humidity

The shape of the target also impacts the performance of the distance sensor. Again, an ultrasonic distance sensor relies on the reflected sound amplitude being sufficient for reliable detection. If the sound wave is not reflected back towards the distance sensor, i.e. reflected away from the distance sensor, then the distance sensor cannot measure the distance. Large flat targets such as boxes, liquid surfaces and the like, which are perpendicular to the distance sensor axis, reflect the sound wave directly back to the distance sensor providing a clear signal. Conversely, reflection of a sound wave off an angled target causes the sound wave to deflect away from the distance sensor making detection impossible.

Round targets provide an interesting case considering that the energy scatters off the surface of the object. Figure 2 demonstrates the expected performance decline given various spherical targets.

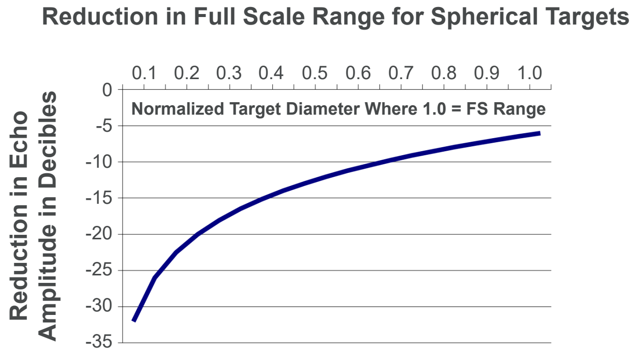


Figure 2: Reduction in Full Scale Range for Spherical Targets

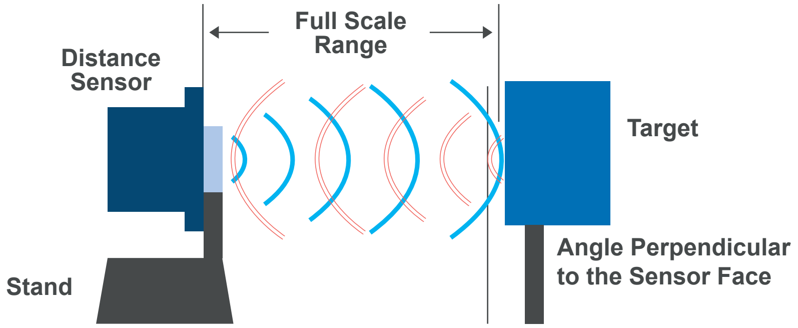
The signal strength of the returned echo drops off as the target size diminishes and as the distance to the target increases. As one might well imagine a basketball at a 5 feet distant will provide a much stronger echo than a golf ball 30 feet away.

For most applications, the target is neither a flat face nor a sphere, dictating the need for a controlled test to evaluate the performance of the distance sensor. The following two step process outlines a simple method to baseline the distance sensor performance for a particular target.

Step 1: Base line the distance sensor performance by mounting the distance sensor into a stand making sure that it is perpendicular to the target. Also make sure that there are no obstructions in-between the distance sensor and the target and that the area around the set up is clear from obstructions.

Determine the full scale range, the point at which the distance sensor's output remains constant and no long responds to increasing distance. That value represents the maximum useful range for the chosen. (See figure 3 below)

Figure 3: Setup for Target Performance Evaluatioins



Step 2: Rotate the target relative to the distance sensor and determine the fall off in range at ever increasing angles as shown in Figure 4.

The full scale range will fall off with increased angles as can be seen in the example plot Figure 5.

In this example, the target was rotated on its axis from a -10˚ to +10˚ and the maximum target distance was measured. The chart provides a convenient means of determining the distance sensors range limitation for a particular target within the application.

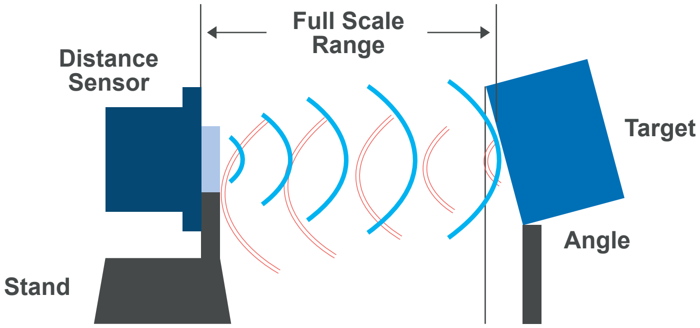


Figure 4: Setup for Skewed Target Performance Evaluations

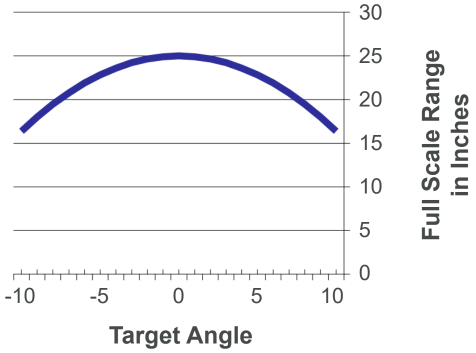


Figure 5: Full Scale Range Verses Angle Example

Motion can impact the performance of an ultrasonic distance sensor, be it standing waves in a fuel tank or objects moving down a conveyor belt. Wave motion creates noise in the measured data because the distance sensor measures one distance at the wave peak and another distance during the wave troughs.

For a typical on highway application, this difference can be as high as 30% of full scale. SSI's ultrasonic distance sensor design compensates for this difference by averaging data and processing the result through a multi tap finite impulse filter. The combination of which minimizes the standing wave noise level to a manageable level with a minimal reduction in the distance sensor's response time.

A second problem in liquid level applications occurs when the liquid washes over the surface of the distance sensor. In this case, the distance sensor becomes a depth sounder, coupling to the fluid and then measuring the distance to the bottom of the tank and back. The speed of sound is roughly 4 times faster in a fluid so the net result is a false reading indicating a quarter of tank.

Moving targets can be a problem especially if they pass by the distance sensor too quickly. SSI's design employs a sampling technique to measure the distance from the distance sensor target once every 50 msecs for distance sensors with a full scale range less than 2 meters and once every 200 msecs for distance sensors with a full scale range of 3 meters. The target will not be detected if it moves past the distance sensor's operating window faster than the sampling rate.

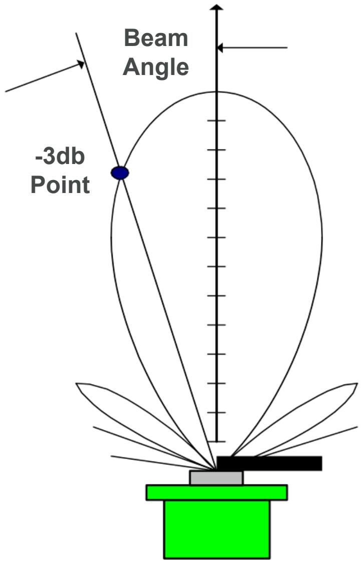
Ultrasonic Sense Element Considerations

By nature ultrasonic sense elements are imperfect devices, their resonant frequency, sensitivity and Q change with temperature. In addition, ultrasonic sense elements continue to ring (oscillate) long after the excitation is removed which can mask near field target detection's. These types of problems, if not managed correctly, can seriously erode the operating window of an ultrasonic distance sensor. SSI's Acu-Trac® system compensates for sense element variation by monitoring the quality of the returned echo signal and then continuously updating the sense elements drive parameters and echo measurement function to correct for changes in sense element performance.

Directivity is achieved by focusing the sound wave into a conical pattern, which expands with increasing distance. The included angle or beam angle is typically 10° to 15° for the SSI ultrasonic distance sensor family. This angle is defined by when sound pressure of the main lobe has dropped off by a –3db from its peak as one moves off the centerline of the ultrasonic distance sensor at a fixed distance.

The impact on the application is that objects located within this pattern will cause reflections that could be misinterpreted by the distance sensor. Conversely, the target of interest must be located within the beam pattern.

The following illustration (Figure 6) is a directivity plot of an ultrasonic distance sensor.



By focusing the sound wave energy the distance sensor is able to reliably discriminate between adjacent targets, reduce noise and scattering of the sound wave. It is important to recognize that targets outside of the propagation pattern cannot be identified by the distance sensor and conversely the distance sensor cannot discriminate between multiple targets located within the sound wave cone.

Transmission Media

The speed of sound changes when traveling through different media. For example, in dry Air at 0 ˚C, the speed of sound is 331.45 m/sec. Where as in Hydrogen at the same temperature, the speed of sound is 1284 m/sec.

This can give rise to significant measurement errors, if the system was designed for Air yet the distance sensor is employed in something other than air.

Gases at 0 °C	Speed of Sound in m/sec
Air, Dry	331.45
Ammonia	415
Carbon Monoxide	338
Carbon Dioxide	259
Chlorine	206
Ethane	308
Ethylene	317
Helium	965
Hydrogen	1284
Hydrogen Chloride	296
Methane	430
Nitrogen	334
Nitrous Oxide	263
Oxygen	316
Sulfur Dioxide	213

Table 1: Speed of Sound in Gases

Vapors at 97.1 °C	Speed of Sound in m/sec
Acetone	239
Benzene	202
Carbon Tetrachloride	145
Chloroform	171
Ethanol	269
Ethyl Ether	206
Methanol	335
Water Vapor	494

Table 2: Speed of Sound in Vapors

Speed of sound compensation is critical for maintaining accuracy. The variations between media types is simply too large to be ignored. SSI's ultrasonic distance sensor although designed for air, can be programmed to compensate for the speed of sound differences encountered with different media.

For applications where the transmission media is not air, the user can compensate by calculating a new full scale distance based upon the speed of sound difference and then modifying the Absolute Quantity Scalar to compensate.

Accoustic Noise

In general, acoustic and vibrational noise is not a problem due to the relatively high frequencies that the distance sensors operate at. However, installations where two distance sensors are placed within each other's field of view can cause problems. The issue occurs when one distance sensor mistakenly reads the echo created by another distance sensor, causing an incorrect measurement to be reported.

How close is too close? Adjacent distance sensors must be at least 3 echo reflections away from each other at their maximum operating distance in order to avoid interference. A good rule of thumb is to space adjacent distance sensors at least 2 times their full scale measurement distance.

References: Donald Massa, March 1999, "Part 2: Optimizing Sensor Selection" Sensors
Gorden Becker, "Velocity of Sound", CRC Handbook of Chemistry and Physics, 54th Edition.

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