Application Note

Ultrasonic Sensing Using LOG Detector Amplifier

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ABSTRACT

Ultrasonic sensing involves using sound waves at frequencies higher than human hearing which is typically above 20KHz to detect object, measure distances or sense presence or absence of any material. Ultrasonic sensing works by emitting ultrasonic wave signal from a transmitter which travels through the medium and as it hits any object the signal partly reflects back, some get absorbed while remaining permeates through the object. This reflected or permeated wave is then detected by the receiver and processed to extract the useful information like the time of flight or the amount of attenuation the signal suffered as it traveled through the material. This article shows how Logarithmic detector like LOG300 can be used in the receive signal chain to process the signal from the ultrasonic receiver for applications like double paper sheet detection, material detection, bubble counter or detection in fluid, material detection and distance or proximity detection.

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1 Introduction

Ultrasonic sensing is a technology that utilizes high-frequency sound waves to detect objects and measure distances. This method is widely used in various applications, including industrial automation, automotive systems, and medical. Ultrasonic sensors emit sound waves at frequencies above the human hearing range (typically above 20kHz). The system mainly constitutes of two parts transmit and receive. Driving an ultrasonic transducer can be done in mainly two ways, either by transformer where higher excitation signal is required or directly using H-bridge or an amplifier where comparatively lower excitation is required. Whereas on receive side, there are different types of gain amplifier which can be used for signal processing like fixed gain, variable gain, time varying gain or a logarithmic (log) gain amplifier. This article demonstrates how a log detector can be incorporated in ultrasonic sensing systems to enhance the dynamic range and sensitivity. By using a logarithmic detector, ultrasonic sensing systems can effectively handle weak echoes and strong signals alike, making sure reliable and accurate measurements.

2 Description

2.1 Basics of Ultrasound Sensing

Ultrasound is sound waves with frequencies higher than the upper audible limit of human hearing (greater than 20KHz) and is a sub-discipline of acoustics.

Ultrasound is not different from normal or audible sound in physical properties, except that humans cannot hear ultrasound. Ultrasound can be further defined as an oscillation in pressure, stress, particle displacement, and particle velocity propagated in a medium with internal elastic or viscous forces. Ultrasound can be viewed as a wave motion in the air or other elastic media.

Ultrasound can propagate through a medium such as air, water, and plasma as longitudinal waves, and also as transverse waves. Ultrasound can be generated by an ultrasonic source, such as the vibrating diaphragm of a transducer which are generally made up of piezo electric material. The ultrasound source creates vibrations in the surrounding medium. As the source continues to vibrate the medium, the vibrations propagate away from the source at the speed of sound, thus forming the ultrasound wave. At a fixed distance from the source, the pressure, velocity, and displacement of the medium vary in time.

The behavior of ultrasound propagation is affected by the relationship between the density and pressure of the medium, which is affected by temperature and determines the speed of sound within the medium. Motion of the medium such that if the medium is moving can increase or decrease the absolute speed of the sound wave depending on the direction of the movement. For example, ultrasound moving through fluid can have speed of propagation increased by the speed of the fluid if the ultrasound and fluid are moving in the same direction.

If the ultrasound and fluid are moving in opposite directions, the speed of the sound wave can be decreased by the speed of the fluid. Medium viscosity determines the rate at which sound is attenuated. For many media, such as air or water, attenuation due to viscosity is negligible. But in other media, such as rubber, paper and soft material like cotton, higher viscosity can result in greater acoustic losses.

Although there are many physical complexities relating to the transmission of ultrasound, at the point of reception, such as a microphone or US transducer, ultrasound is simply interpreted as pressure and time with the properties like frequency or wavelength, amplitude, sound pressure or intensity, speed of sound, and direction.

The speed of sound depends on the medium the waves pass through and is a fundamental property of the material. The speed of sound is proportional to the square root of the ratio of the bulk modulus of the medium to the density. These physical properties and the speed of sound change with ambient conditions, such as temperature and humidity.

The Sound Pressure Level, or SPL, is defined as follows,

$L_p = 10\log(p^2/pref^2)$

where

p = rms sound pressure (Pa) pref=reference pressure, 2×10−5Pa

Commonly used reference sound pressures are 20 micro pascals in air and one micro pascal in water. When sound travels through a medium, the sound pressure diminishes with distance. Designed for, a sound pressure is only reduced by the spreading of the wave. However, real world factors further reduce sound pressure.

This additional production results from scattering and absorption. Scattering is the reflection of the sound and directions other than the original direction of propagation. While the absorption is the conversion of sound energy to other forms of energy. The combined effect of scattering and absorption is called attenuation. Ultrasonic attenuation is the decay rate of the wave as ultrasonic propagates through a material.

Ultrasonic waves are reflected at boundaries where there is a difference in acoustic impedance of the materials on each side of the boundary. The acoustic impedance of a material is defined as the product of the density and acoustic velocity. Acoustic impedance is important in the determination of acoustic transmission and reflection at the boundary of two materials having different acoustic impedance, the design of ultrasonic transducers, and assessing absorption of sound in the medium.

This difference in acoustic impedance is commonly referred to as the impedance mismatch. The greater the impedance mismatch, the greater the percentage of energy that can be reflected at the interface or boundary between one medium and another

Ultrasonic Sonar Cross Section, or SCS, is a measure of how detectable an object is by sonar. A larger SCS indicates that an object is more easily detectable. An object reflects a limited amount of sonar energy back to the source. The factors that influence this include the material of which the target is made, the size of the target relative to the wavelength of the emitted sonar signal, the absolute size of the target, and the shape of the target.

The shape of the target also affects the incident angle, or the angle at which the sonar beam hits a particular portion of the target and the reflected angle, the angle at which the reflected beam leaves the part of the target hit. The SCS of an object is the cross-sectional area of a designed for reflecting sphere that can produce the same strength reflection as the object in question. Bigger sizes of this imaginary sphere can produce stronger reflections. The SCS of a sonar target is an effective area that intercepts to transmitted sonar power and then scatters that power isotropically back to the sonar receiver.

2.2 Advantages and Disadvantages of Ultrasonic Sensing

Ultrasonic sensing has several advantages over other sensing technique like IR based. The US transducer can be made with water-proof enclosure and hence are resistant to moisture and rain. The US transducer also have robust performance through dirt, dust, and debris and can operate at both high and low temperature.

Unlike IR based sensor, the US transducer can detect both opaque and transparent object with same accuracy and are equal sensitivity to both light and dark colored object

Nevertheless, there is one major disadvantage of US sensing, the US sensing is generally unable to detect objects with similar acoustic impedance to transmission medium. For example, in an air-coupled application, the ultrasonic energy can pass through, be absorbed, or scattered by soft, low-density objects.

2.3 Ultrasonic Transducer

Ultrasonic transducers are generally piezoelectric transducer which works on the principle of piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge. While transmitting, the ultrasonic transducer converts the electrical input signal to mechanical vibrations which results in generation of ultrasound, and while receiving, the ultrasonic transducer converts the mechanical vibrations cause by ultrasound hitting the transducer’s active element back into electrical energy

2.3.1 Transducer Construction

There are mainly two types of transducers available: *closed-top* and *open-top*.

Type selection needs to be based on the ambient **environment** conditions.

Table 2-1. Close top vs Open top: Benefits and Drawbacks

Type	Close top	Open top
Benefits	• Piezoelectric membrane protected against water (hermetically sealed), heat, and humidity • Constructed to mitigate ESD strikes • Designed for outdoor or harsh environments	• Piezoelectric membrane directly couples to air for • Increased receiver sensitivity • Small driving voltage to generate maximum SPL • Large off-the-shelf selection for purchase • Low-cost
Drawbacks	• Requires large driving voltage enabled by transformer • Limited off-the-shelf selection for purchase • High-cost	• Limited to indoor or protected environments

2.3.2 Transducer Frequencies

Most piezoelectric ultrasonic transducer are optimized to work at a particular narrow band of frequency range, this frequency is known as resonance frequency and depends on the construct of the transducer. For most air-couples application this ranges from 30Khz to 480Khz while liquid level sensing, transducers in the 1MHz range are often used. The transducer frequency selection needs to be based on application and requirement.

As the frequency increases the resolution and directive also increase but at the same time reduces the distance the sound signal can travel. This is because the attenuation of higher frequency signal is much higher compared to lower frequency signal as the frequency travels through a medium.

Table 2-2. Low Frequency vs High Frequency : Benefits and Drawbacks

Type	Low Frequency	High Frequency
Benefit	• Maximize long range performance • Large off-the-shelf selection for purchase	• Maximize resolution (typically <5mm) • Short blind-zone in mono static topology because of reduced ring decay time • Transmission concentrated into forward facing
Drawbacks	• Long blind-zone in mono static topology • Low resolution (typically >5mm)	• Reduced maximum detectable range due to higher attenuation • Limited off-the-shelf selection for purchase

2.4 Transducer Topologies

There are two different topologies in which transducer can be configured for transmitting and receiving the ultrasonic signal: monostatic or bistatic. These must be based on the type of application. Monostatic topology is when a single transducer both transmits an echo and listens for returning echoes. This is the lower-cost method preferred in most applications. The drawback of the monostatic transducer topology is that the excitation ringing-decay of the sensor creates a blind zone and the transducer topology cannot sense the reflected echo during this time and hence limits the minimum detection range. In a monostatic configuration, this blind zone can be reduced by adding a damping resistor.

Other topology is the bistatic topology where are two separate transducers are used – one for transmitting and one for receiving. These are comparatively expensive design. These are generally used where we need to measure the attenuation of the signal as the signal permeates through a medium and reflected echo signal does not have any useful information. For ToF application the drawback to using the bistatic approach is that additional calibration required, as the designer must consider the angle of the incoming echo at the receiver when computing the time-of-flight calculation.

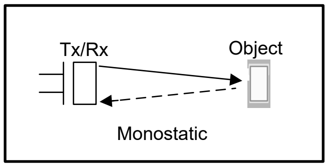


Figure 2-1. Monostatic

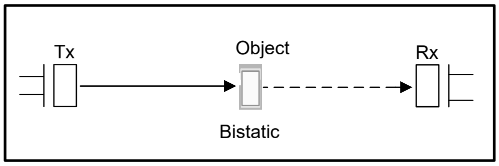


Figure 2-2. Bistatic Configuration 1

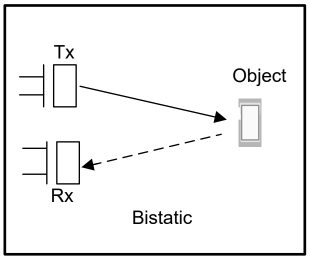


Figure 2-3. Bistatic Configuration 2

2.5 Blind Zone Effect on Minimum Distance

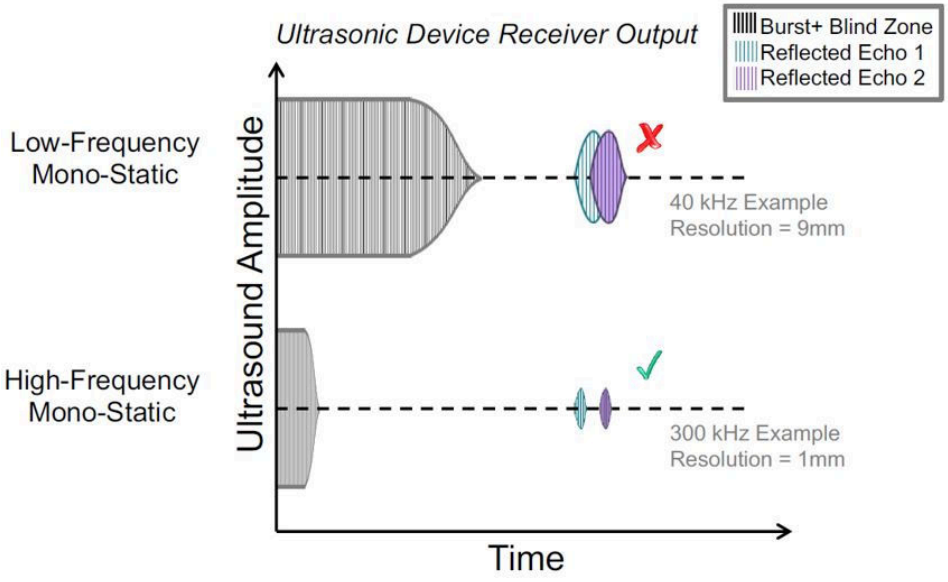


Figure 2-4. Blind Zone Effect on Minimum Distance

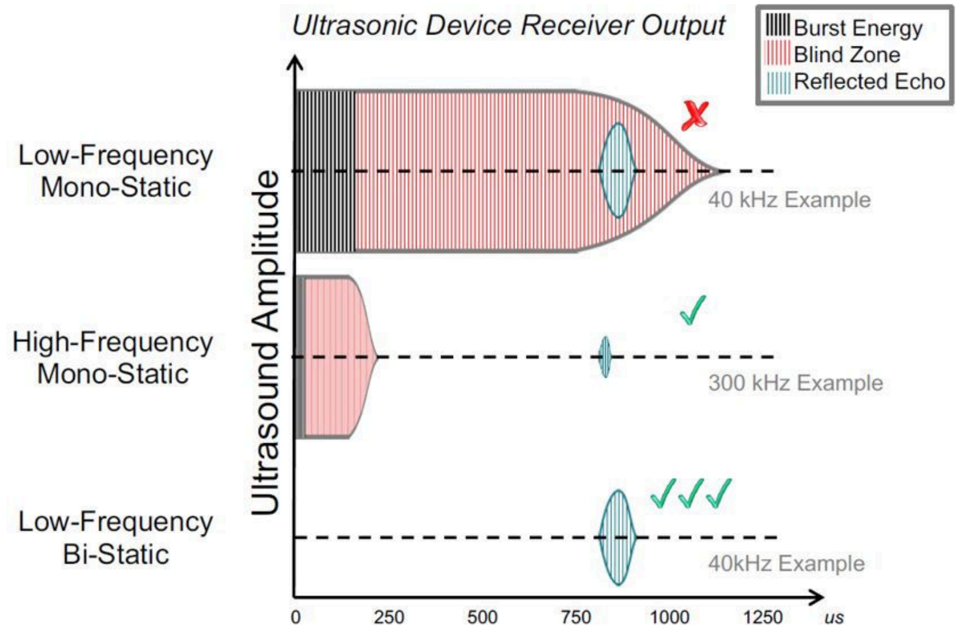


Figure 2-5. Accuracy for Multi-Object Detection

2.6 Transducer Drive

There are mainly two ways in which an ultrasonic transducer can be driven. The first one is the Transformer drive and second is direct drive and which type to choose mainly depends on the voltage requirement for exciting the transducer.

Transformer drive as the name suggest uses a step-up transformer to drive the transducer. The primary coil of the transformer is excited with low voltage signal and secondary side (which has a much higher voltage swing) drives the transducer. With transformer drive one can achieve the transducer excitation voltage beyond 100Vpp and so are generally preferred where the sound pressure level requirement is high like for application which requires measuring or detecting object at large distances.

Direct drive uses a H bridge (full or half) driver or an amplifier to directly drive the transducer. So in this the maximum excitation voltage is limited to the power supply of the system. These are mainly used for application where we don’t need large sound pressure level.

Type of mode to select also depends on the construction type of the transducer. Many open-top transducers do not require more than tens of volts to generate the maximum transmittable sound pressure level (SPL), so a transformer is not necessary, and a direct-driver mode is recommended. Closed-top transducers can also be excited in the direct-drive mode, but the transducers effective range is limited due to the typical requirement of hundreds of volts to generate the maximum transmittable SPL.

Table 2-3. Transformer Drive vs Direct Drive

Type	Transformer	Direct
Benefits	• Able to maximize drive requirements for closed-top transducers (beyond 100Vpp) • Equivalent circuit enables de/tuning for short range • Fixed and tunable coil types available • Center-tap push-pull or single-ended available	• Able to maximize drive requirement for open-top transducers • Able to drive closed-top transducer for short range applications • Half-bridge or full-bridge drivers available • Low-cost and small footprint
Drawbacks	• Additional calibration and tuning required at mass production • High-cost and large footprint	• Short range tuning limited to damping resistor

2.7 Ultrasonic Echo and Signal Processing

TI recommends to drive transducers with a sine or square wave at the center frequency to achieve the best results. Most integrated designs have an output driver consisting of low-side drivers to drive a transformer in a transformer-drive situation, or FETs in an h-bridge configuration for a direct drive design. After the transducer sends out an echo at the resonant frequency, the system must then listen for return echoes which are a result of an object in the transducer's field of view. Ultrasonic systems typically filter the return echo to remove noise and gain the signal up before going to an ADC. Some ways to gain the ultrasonic system are as follows.

2.7.1 Digital Gain or Fixed Gain

Apply a fixed gain to the entire ultrasonic echo. The main drawback of type of gain is that the system sometimes cannot handle the wide range of signal amplitudes effectively leading to poor performance in detecting both very weak and very strong signal.

2.7.2 Time-Varying-Gain

Apply a gain that is dependent on how far out an object is. Often, objects that are further out in time produce a weaker echo response and objects that are closer produce a stronger echo response. To combat this, to prevent saturation of the close signals, and to be able to identify the further objects, one can choose to gain the system such that a small gain is applied early in time, and a larger gain is applied further out in time. This gives the user flexibility to configure the gain based on the system requirements.

2.7.3 Automatic Gain Control or Logarithmic Amplifier

A logarithmic amplifier approach is a way to achieve automatic gain control when dealing with input signals that are both high and low in amplitude. A log amp gains an input signal based on the log scale which helps get a stronger echo response from weak signals while also appropriately gaining the strong signals but preventing saturation, similar to the time-varying-gain approach. Whereas the time-varying-gain method is dependent on where an object is in time, the logarithmic amplifier is dependent on the actual echo of the input signal with no dependency on time.

2.7.4 Logarithmic Amplifier vs Logarithmic Detector

The primary difference between a log detector and a logarithmic (log) amplifier lies in the way the detector and amplifier processes the signal and the specific applications. A log amplifier provides an output that is proportional to the logarithm of the input signal's amplitude. The log amplifier is designed to handle a wide dynamic range of input signals by compressing them logarithmically. Log amplifiers are commonly used in applications where signal compression is needed, such as in RF signal processing, audio level compression, and true RMS detection. A log detector, also known as a demodulating log amplifier, provides an output that is proportional to the logarithm of the envelope of the input signal. A log detector essentially demodulates the signal and then applies a logarithmic function to the envelope. A log detector generally used to measure signal strength over a wide dynamic range.

In summary, while both devices perform logarithmic functions, a log amplifier works directly on the input signal's amplitude, whereas a log detector focuses on the envelope of the input RF signal.

The following paragraphs of this article shows how a Logarithmic detector can be used at the receive side of the signal chain to achieve better performance in terms of input sensitivity, dynamic range, noise and gain control as compared multi-gain stage traditional op-amps configuration in various ultrasonic sensing applications.

3 LOG Detector Amplifier and the Advantages Over Conventional Opamps

Using a logarithmic detector amplifier over a conventional operational amplifier (op-amp) for ultrasonic sensing offers several advantages:

- **Wide Dynamic Range**
  Logarithmic detectors can handle a wide range of signal amplitudes, making them a designed for application where the signal strength can vary significantly. This is particularly useful in ultrasonic sensing where the received signal strength can vary due to distance, material properties and surface texture.
- **Improved Sensitivity**
  Log detectors can detect very small changes in signal amplitude, which enhances the sensitivity of the ultrasonic sensor. This is beneficial for detecting weak echoes that can be missed by conventional op-amps.

- **Non Linear Output**
  The output of a log detector is proportional to the logarithm of the input signal, which means the output can compress a large range of input signals into a smaller, more manageable output range. This makes the process easier to analyze the signals.
- **Noise Reduction**
  Logarithmic detectors can help reduce the impact of noise on the signal as compared to multi stage fixed gain amplifier. Since they compress the signal range, they can make the process easier to distinguish between the actual signal and noise.

These advantages make logarithmic detectors a preferred choice in many applications, especially where high sensitivity and wide dynamic range are required like in ultrasonic sensing.

4 Application

4.1 Double Paper Feed and Paper Thickness Detector

Ultrasonic double feed detection technology is a sensor-based mechanism aimed to prevent multiple papers from being fed into a printer or scanner simultaneously. This not only increases the efficiency and accuracy of system's operations but also contributes to preserving the integrity of the documents being printed or scanned.

This section provides an overview of the working principle of double paper feed detection and how the detection can be implemented using a log detector amplifier

Ultrasonic double paper feed detection works by using sound waves to detect the presence and thickness of paper in a feed system.

Transmitters and Receivers: The system consists of two ultrasonic transducers which are placed on either side of the paper feed path. One acts as a transmitter, emitting ultrasonic sound waves, while the other serves as a receiver.

- **Sound Wave Emission**
  The transmitter sends out ultrasonic sound waves that travel through the air and hits the paper where a part of the sound wave gets absorbed, some gets reflected and while remaining permeate through.
- **Signal Reception and Detection**
  The receiver picks up the transmitted sound waves. If there is only one sheet of paper, the sound waves can have a certain strength. When two sheets of paper are present, the paper absorb more sound energy, causing the transmitted signal to be weaker. When more than two sheets are there the signal is even weaker. The receiver detects this change in amplitude and based on that, the system determines whether a single sheet or multiple sheets have been fed into the machine.

This technology is crucial for preventing errors in processes that involve multilayer feeds, such as in printing or packaging industries, where the process makes sure of smooth operation and reduces material waste.

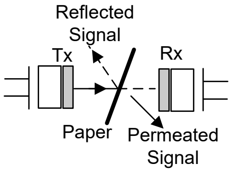


Figure 4-1. Paper Detection

4.1.1 Schematic Implementation

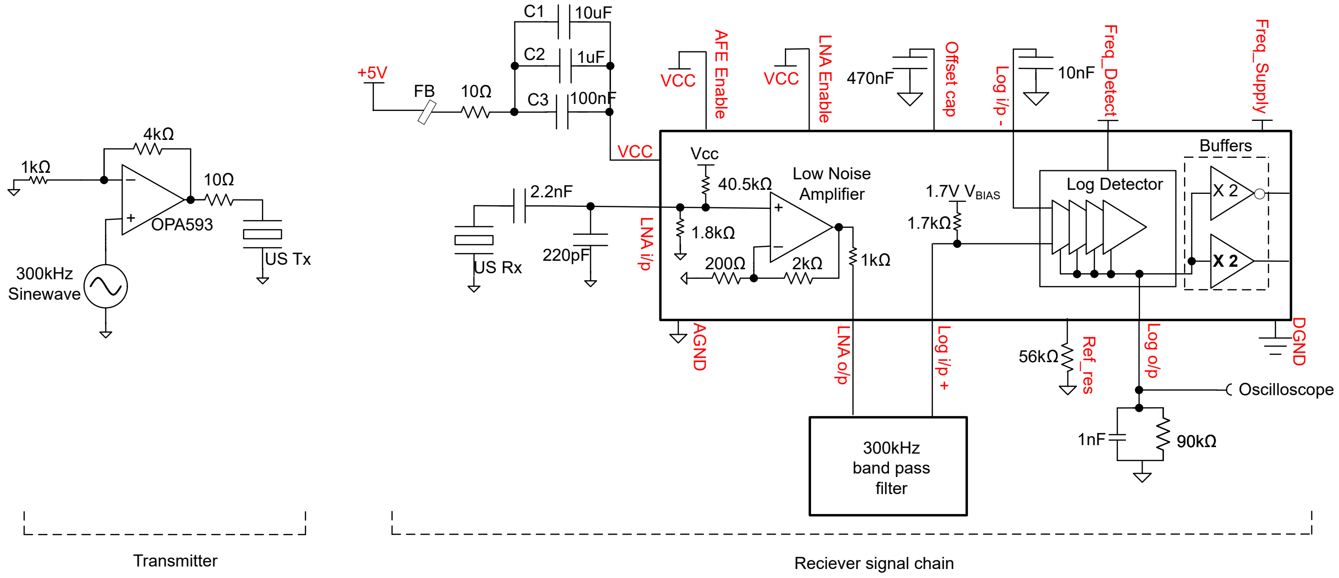
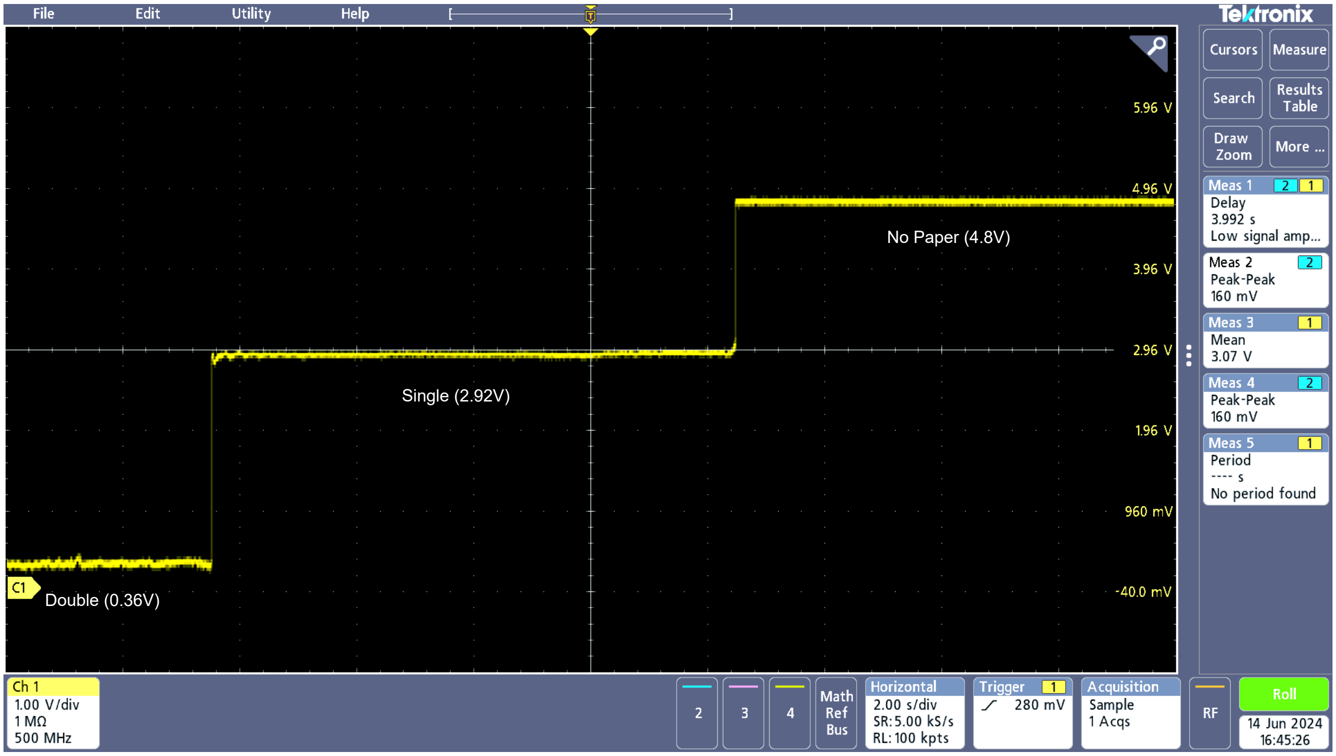


Figure 4-2. Bi-Static Ultrasonic Sensor Circuit

Lab Setup

Results



No Paper (4.8V)

Single (2.92V)

Double (0.36V)

Meas 1: Delay 3.992 s, Low signal amp...

Meas 2: Peak-Peak 160 mV

Meas 3: Mean 3.07 V

Meas 4: Peak-Peak 160 mV

Meas 5: Period ---- s, No period found

Ch 1: 1.00 V/div, 1 MΩ, 500 MHz

Horizontal: 2.00 s/div, SR:5.00 kS/s, RL:100 kpts

Trigger: 1, 280 mV

Acquisition: Sample, 1 Acqs

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Figure 4-3. Double, Single, and no Paper - 100 GSM

4.1.2 Material Thickness Detector

Material thickness detection also works in a principle very similar to double paper feed detection and the same setup can be used for this application as well. This article demonstrate the thickness detection of papers with different GSM (gram per square meter) count. Higher the GSM, higher can be the weight and thickness of a paper.

Similar to the double feed detection, in this application also, the material (here paper) is placed between the two ultrasonic transducer (Tx and Rx). As the transmitted signal passes through the paper, the signal gets attenuated and the strength of received at the Rx depends on the thickness of the paper. Thicker the paper, more signal can get absorbed resulting in higher attenuation. This can be detected as a drop in the received signal strength.

Table 4-1 shows the output signal of the LOG300 at the receive signal chain with respect to paper of different thickness and number of such paper placed in between the two transducer

Table 4-1. LOG300 Output (V) vs Paper Thickness

No of Sheet	70GSM Paper	100GSM Paper	200GSM Paper	270GSM Paper
No paper	4.8V	4.8V	4.8V	4.8V
Single	3.1V	2.92V	2.76V	2.6V
Double	0.38V	0.36V	0.33V	0.31V

As shown, the paper thickness increases the signal attenuation also increases resulting in lower voltage at the LOG300 output

4.2 Bubble Detector

A bubble detector is used in systems where air or gas bubbles are unwanted in the fluid flowing through a pipe, for example for critical medical equipment like dialysis machines, infusion pumps, and blood transfusion systems. Beside this, a bubble detector can also detect the development of foams in a fluid.

The major advantage of using an ultrasonic transducer for bubble detection is that measuring method is non-invasive and functions through the tubing wall. The sensor has no direct contact to the fluid, which prevents a potential risk of contamination or leakages. So, the bubble detection can easily be mounted on top of the tubing without any additional tools or modification to the existing system.

For this application also the two transducers are used in bi-static configuration and are placed on either side of the tube, one for transmitting and other for receiving.

When there are no bubbles, the ultrasonic signal passes through the tube and the fluid without much attenuation, but if any bubble is present in the fluid and as the bubble passes in between the transducers, the ultrasound signal gets scattered or reflected as the bubbles hits the bubble as a result the signal reaching the receiver get attenuated. This attenuation in the signal can be detected by the receiver circuit and can be processed to count the number of bubbles, the size, and even the volume of air in the bubble.

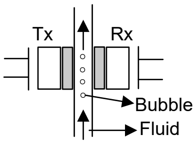
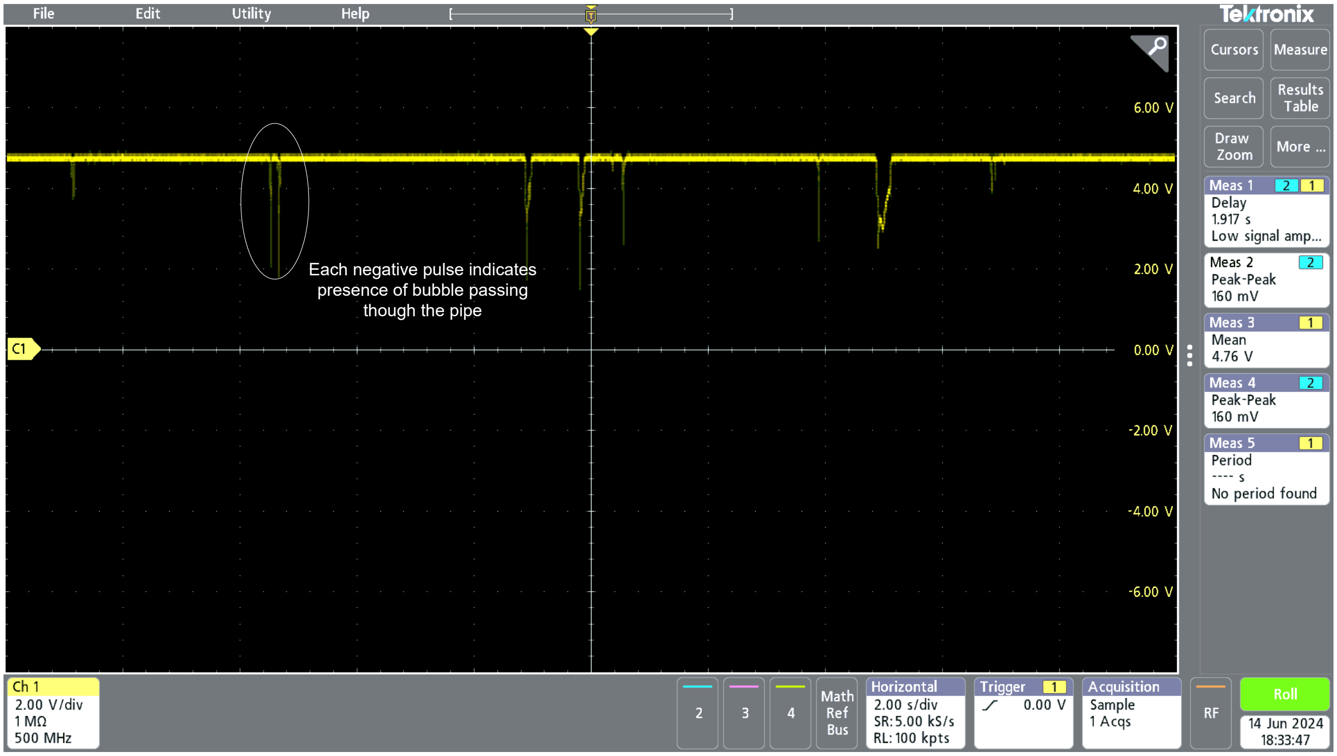


Figure 4-4. Bubble Detection



Each negative pulse indicates presence of bubble passing though the pipe

Meas 1
Delay
1.917 s
Low signal amp...

Meas 2
Peak-Peak
160 mV

Meas 3
Mean
4.76 V

Meas 4
Peak-Peak
160 mV

Meas 5
Period
---- s
No period found

Ch 1
2.00 V/div
1 MΩ
500 MHz

Horizontal
2.00 s/div
SR: 5.00 kS/s
RL: 100 kpts

Trigger
0.00 V

Acquisition
Sample
1 Acqs

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18:33:47

Figure 4-5. Bubble Detector Result

4.3 Material Detection

Material detection works by sending ultrasonic waves into a material, which bounce back when encountering boundaries or defects. Based on the type of material, the reflected echo can have certain strength. Softer material like fabric or carpet can absorb more sound wave resulting in weaker echo as compared to hard material like ceramic tile or wood. The system analyzes the reflected echoes to identify the relative strength of the received echo which can then be processed to infer the type of material.

For this application the transducer is setup in monostatic configuration, that means same transducer first transmit a burst of ultrasonic pulses and then wait for the echo.

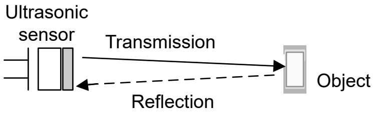


Figure 4-6. Monostatic Sensor

Figure 4-7 shows how an ultrasonic transducer can be configured with LOG300 and a driver circuit for operating an ultrasonic transducer in a monostatic configuration

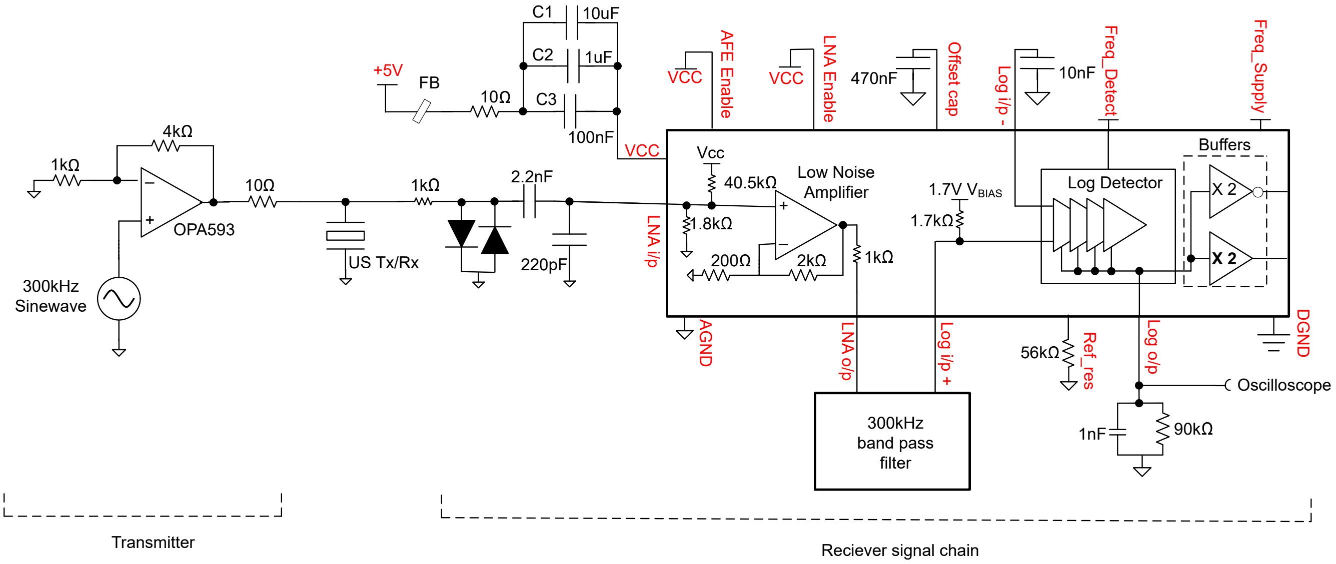
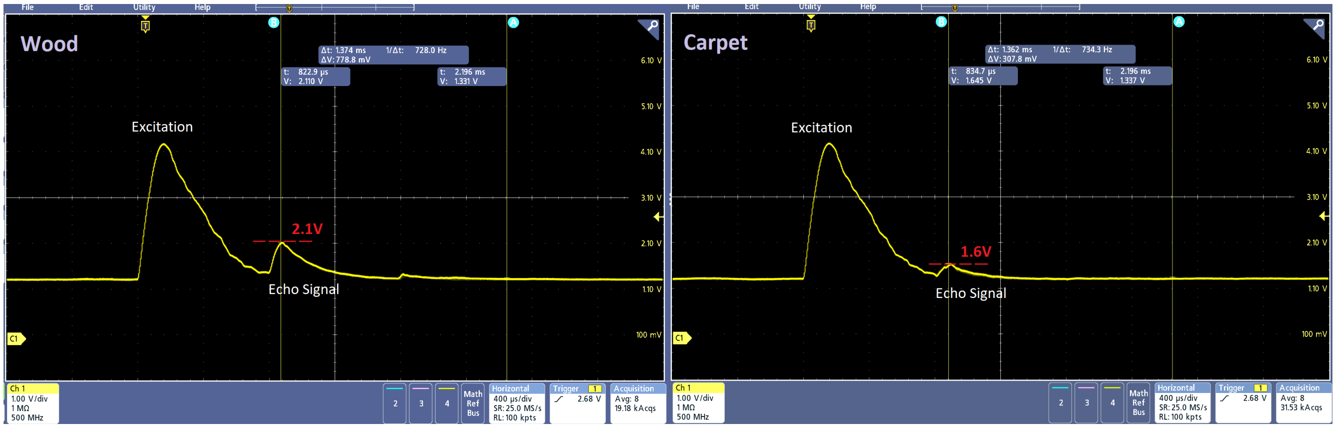


Figure 4-7. Monostatic Ultrasonic Sensor



Δt: 1.374 ms 1/Δt: 728.0 Hz
ΔV: 778.8 mV
t: 822.9 µs
V: 2.110 V
t: 2.196 ms
V: 1.331 V
Ch 1
1.00 V/div
1 MΩ
500 MHz
Horizontal
400 µs/div
SR: 25.0 MS/s
RL: 100 kpts
Trigger 1
2.68 V
Acquisition
Avg: 8
19.18 kAcqs

Δt: 1.362 ms 1/Δt: 734.3 Hz
ΔV: 307.8 mV
t: 834.7 µs
V: 1.645 V
t: 2.196 ms
V: 1.337 V
Ch 1
1.00 V/div
1 MΩ
500 MHz
Horizontal
400 µs/div
SR: 25.0 MS/s
RL: 100 kpts
Trigger 1
2.68 V
Acquisition
Avg: 8
31.53 kAcqs

Figure 4-8. Wood vs Carpet Detection Result

4.4 Distance or Proximity Detection

Distance detection using ultrasonic sensor works on the principle of time-of flight principle which is based on measuring the time taken for the ultrasonic signal to travel from source to an object (whose distance has to be measured) and back to the receiver. For this application, both Monostatic and Bi-static configuration of the sensor can be used but for this demonstration purpose, this article shows monstatic configuration. The same hardware setup shown in material detection can be used here as well. The difference is that, here instead of measuring the amplitude of echo signal we measure the time taken for the transmitted signal to reach back the receiver after getting reflected from the object. Here the total distance the signal travels is twice the distance between the sensor and the object.

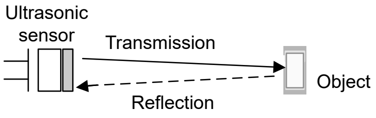
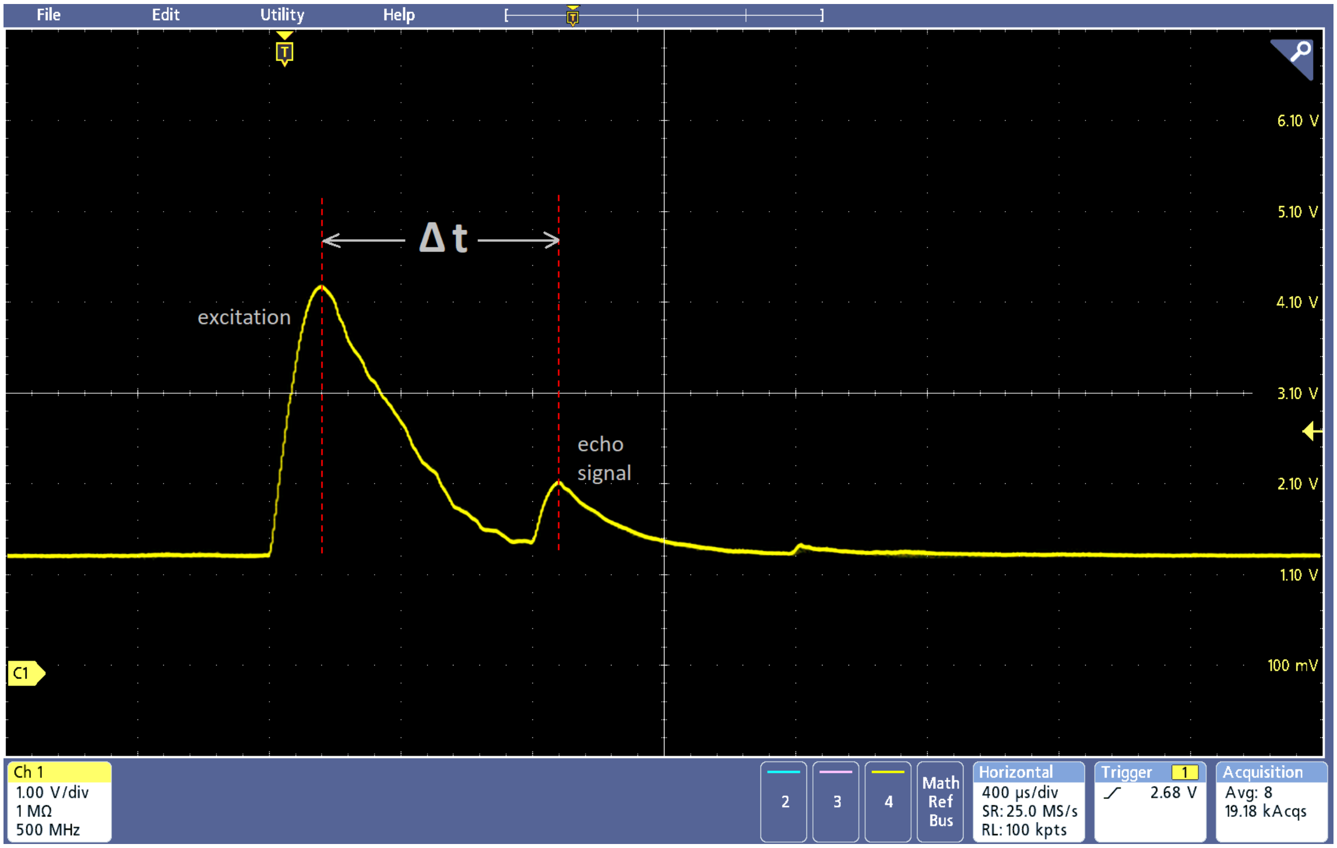


Figure 4-9. Monostatic Sensor

The total time taken is called the time of flight and is denoted by Δt in Figure 4-10. The first pulse here is the excitation or transmitted signal and the second one is the echo signal. Speed of sound in air is around 343m/s, total time of flight for round trip of the signal is Δt, so the distance of the object from the sensor can be given by d= (343m/s x Δt)/2



Ch 1
1.00 V/div
1 MΩ
500 MHz

Horizontal
400 µs/div
SR: 25.0 MS/s
RL: 100 kpts

Trigger 1
2.68 V

Acquisition
Avg: 8
19.18 kAcqs

Figure 4-10. Distance or Proximity Detection

5 Summary

Ultrasonic sensing technology, leveraging the capabilities of logarithmic detector amplifiers, has emerged as a pivotal design in various industrial and medical applications. This technology excels in scenarios requiring precise detection and measurement, such as paper feed detection, bubble detection, material detection and proximity/distance detection.

In summary, the integration of logarithmic detector amplifiers in ultrasonic sensing systems significantly enhances the performance across diverse applications. This technology not only improves detection accuracy but also makes sure of robustness and reliability while reducing the system complexity, making this indispensable in modern industrial or medical environments.

6 References

- Texas Instruments, *Ultrasonic Sensing Basics*, application note.
- Texas Instruments *Precision labs series: Ultrasonic sensing*, video series.

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