Ultrasonic Piezoelectric Sensor

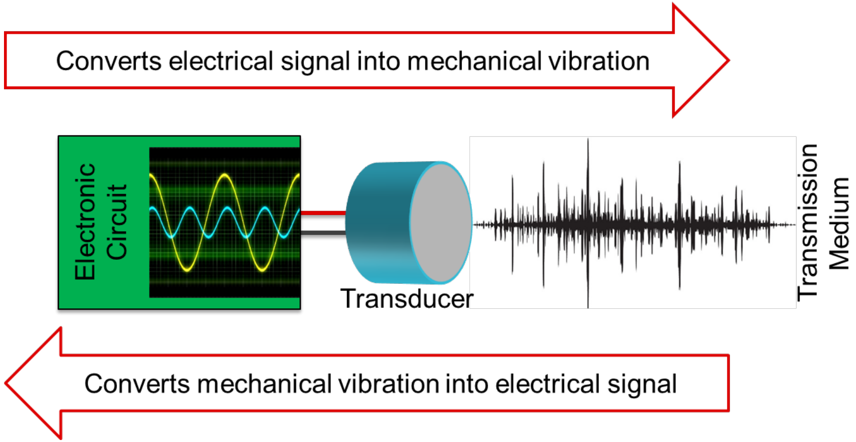
TI Precision Labs – Ultrasonic Sensing

Presented by Akeem Whitehead

Prepared by Akeem Whitehead

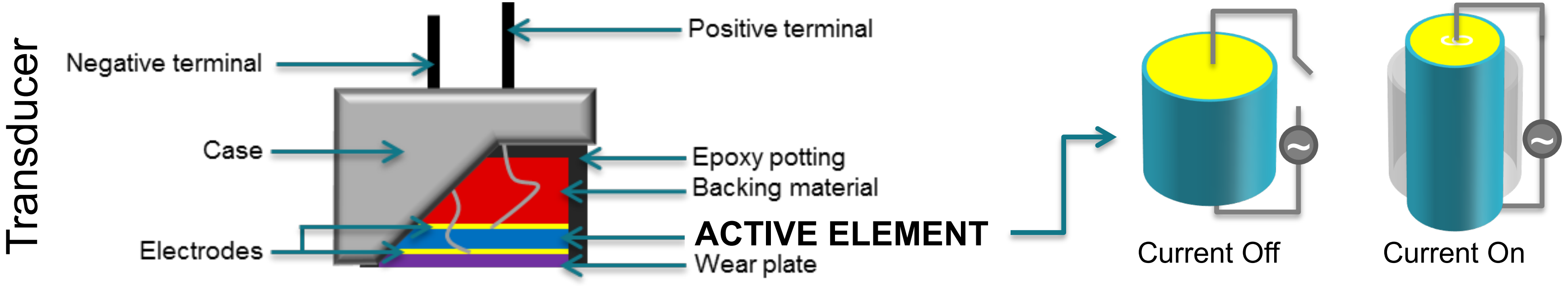
Definition of Piezoelectric Sensor

- A piezoelectric transducer (abbreviated XDCR):
  - uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge.
  - uses the conversion of electrical pulses to mechanical vibrations, and the conversion of returned mechanical vibrations back into electrical energy for the creation and detection of ultrasound.



Piezoelectric Active Element

- The **active element** is the part of the transducer that converts energy between the acoustic and electrical domains.
- When an electric field is applied across the active element, the polarized molecules align with electric field to result in induced dipoles. This alignment causes the material to changes dimensions, a phenomenon known as **electrostriction**.

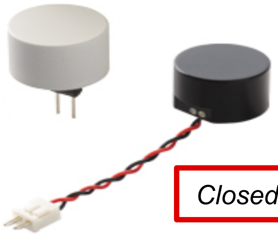


- Thickness of active element is determined by desired frequency of the transducer:
  - Piezoelectric active element is cut to a thickness that is ½ the desired radiated wavelength.
  - *The higher the frequency, the thinner the active element.*

Transducer Construction

- Two types of transducers are available: *closed-top* and *open-top*
- Type selection should be based on the ambient **environment** conditions.
  - Will the transducer be exposed to dust, rain, mud, dirt, snow, ice, etc.?

Type	Closed-top	Open-top
Benefits	• Piezoelectric membrane protected against water (hermetically sealed), heat, and humidity • Constructed to mitigate ESD strikes • **Suitable 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
Disadvantages	• Requires large driving voltage enabled by transformer • Limited off-the-shelf selection for purchase • High-cost	• **Limited to indoor or protected environments**



Closed-top

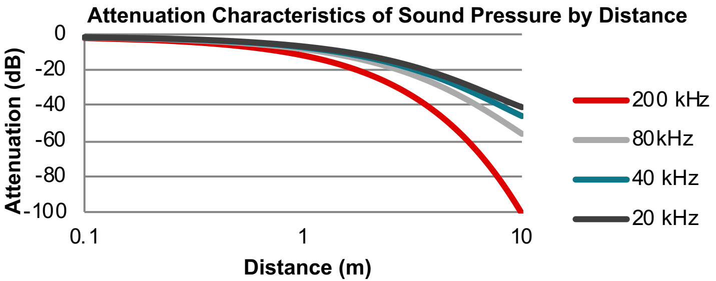
Open-top

Transducer Frequencies

- The resonant frequency of most air-coupled transducers ranges from 30 to 480 kHz
- Frequency selection should be based on the **long range** requirement

↑ ***Frequency*** *:: ↑ Resolution :: ↑ Narrower Directivity :: ↑ Attenuation :: ↓* ***Distance***

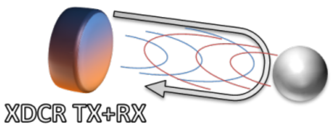
Type	Low Frequency (<100 kHz)	High Frequency (>100kHz)
Benefits	• Maximize long range performance • Large off-the-shelf selection for purchase	• Maximize resolution (typically <5mm) • Short blind-zone in monostatic topology • Transmission concentrated into forward facing direction (no side lobes)
Disadvantages	• Long blind-zone in monostatic topology • Low resolution (typically >5mm) • Prone to common in-band frequency aggressors	• Reduced maximum detectable range due to fast attenuation • Limited off-the-shelf selection for purchase



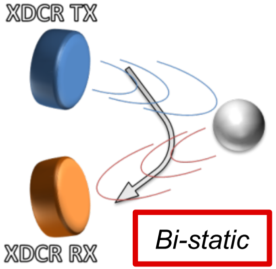
Transducer Topologies

- Two transducer topologies are available: mono-static or bi-static
- Topology selection is primarily dependent on the **short range** requirement
  - Will the system need to reliably detect ~0cm?

Type	Mono-static	Bi-static
Benefits	• Single transducer element can be transmit echo, and then listen for returning echoes • No need to consider spacing and angular compensation as with separate elements • Low-cost and small solution size	• Dedicated transmitter can generate more SPL • Dedicated receiver element is more sensitive and receptive of returning ultrasound • No blind zone allows for near 0cm detection • Can be used for trip/intercept applications
Disadvantages	• Excitation's ringing-decay creates an initial blind zone, limiting minimum detectable range • Limited to roundtrip ToF applications	• ToF roundtrip calculation must factor in angle of incoming echo at receiver • High-cost and larger solution size

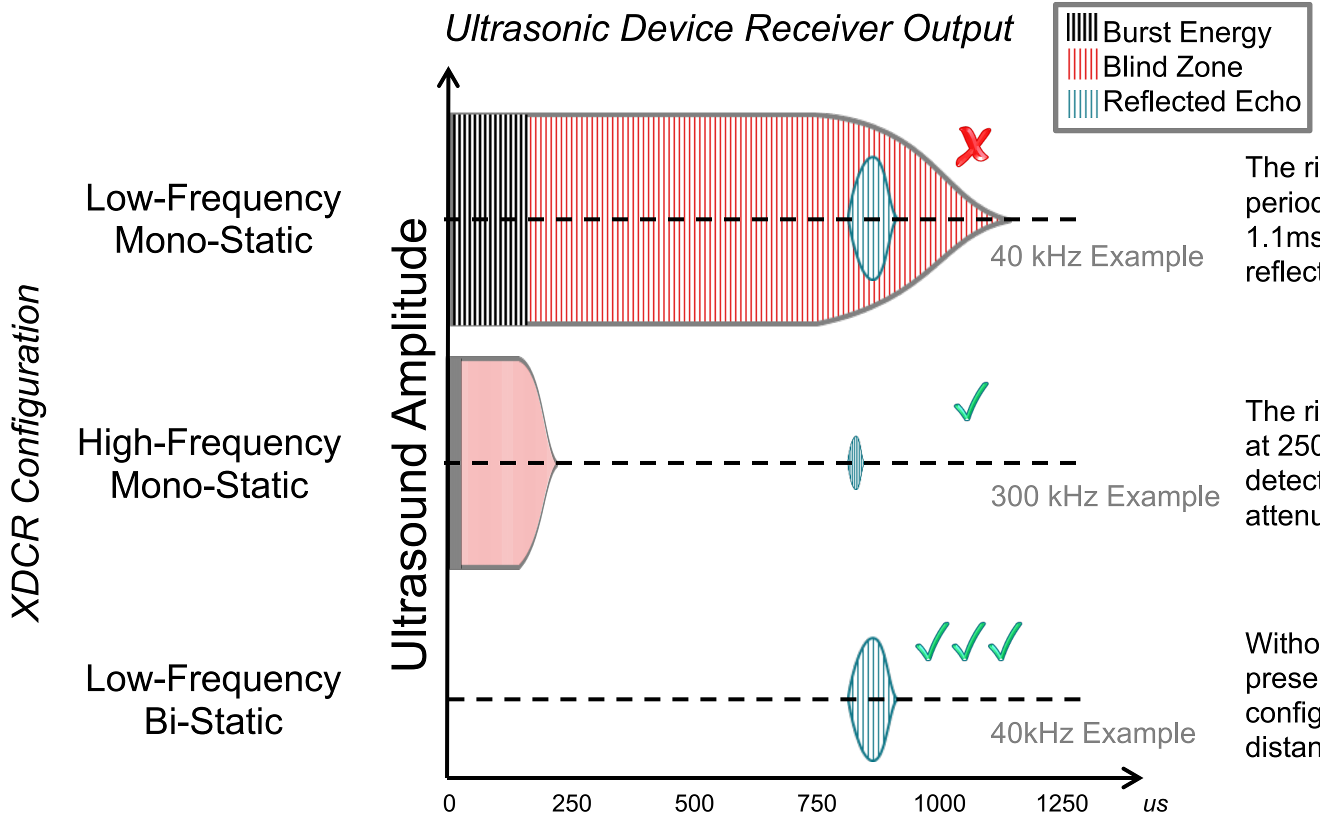


Mono-static



Bi-static

Blind Zone Effect on Minimum Distance



RESULTS

The ring-decay oscillates for an extended period, causing the blind zone to settle at 1.1ms. The device cannot detect the reflected echo received at 800us.

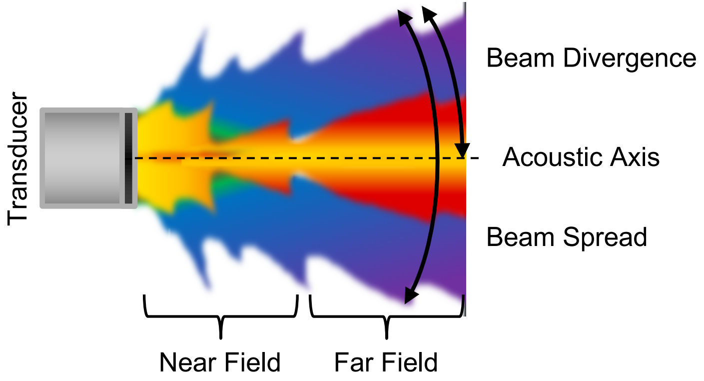
The ring-decay oscillates and settles quickly at 250us. Though the reflected echo can be detected at 800us, the amplitude is more attenuated due to the high-frequency.

Without the burst and ring-decay energy present at the receiver, the bi-static configuration offers the best case minimum distance detection.

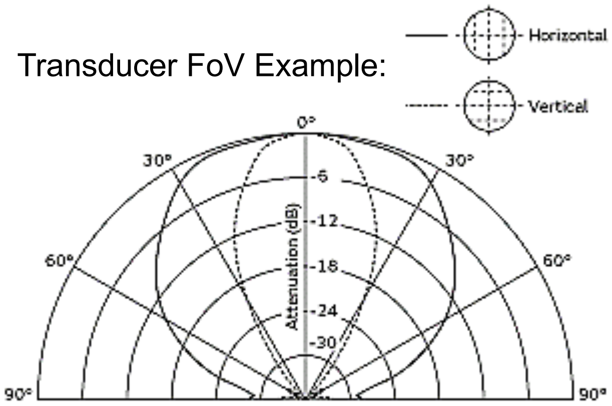
Transducer Field-of-View

The field-of-view (FoV) determines the volumetric space the transducer can emit to and detect objects within.

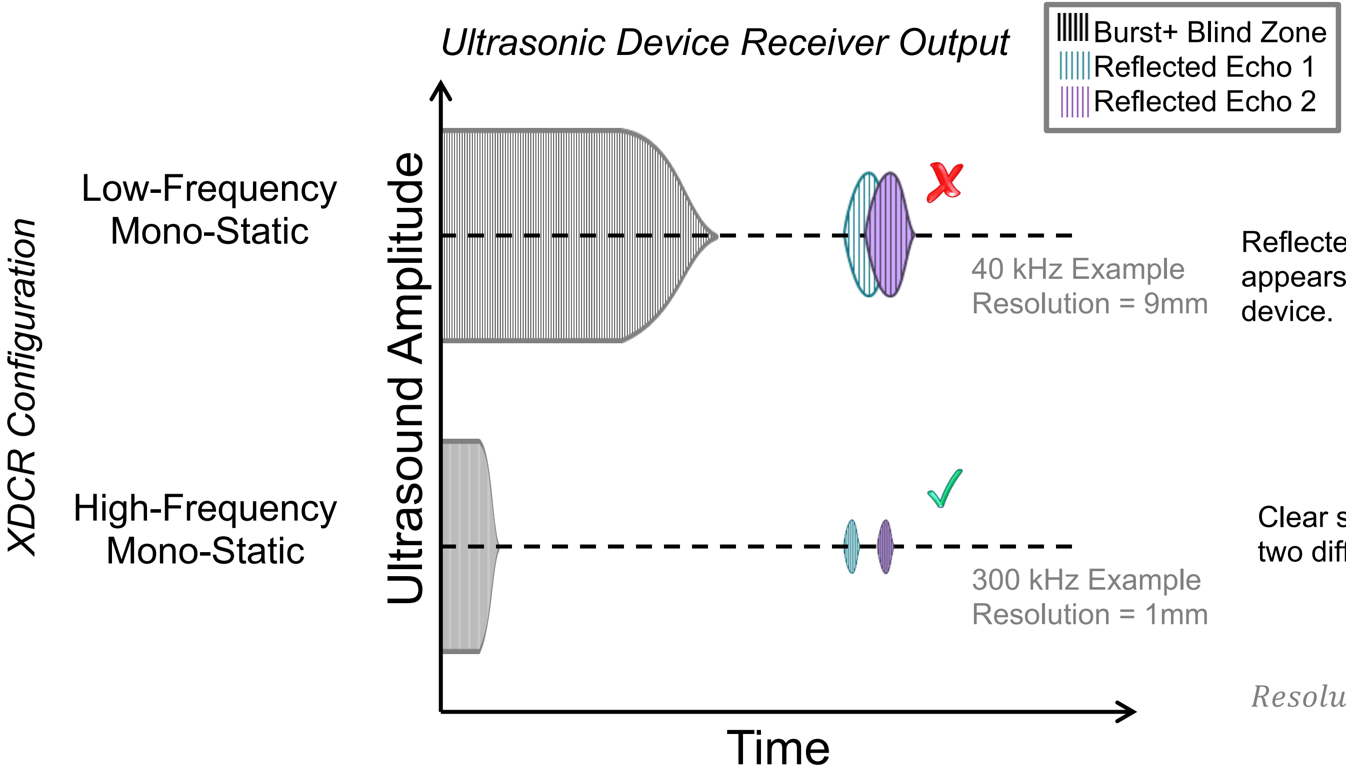
- Ultrasound originates from surface of the piezoelectric active element, not a single point.
  - Round piston source transducers emit a cylindrical sound field, but the ultrasound energy spreads outwards through propagation of the medium.
- Beam spread results in the field-of-view specification, and is also referred to as beam divergence or ultrasonic diffraction.
- Maximum SPL is always along the centerline acoustic axis in the forward facing direction.
- *"What transducer parameters affect beam spread?"*
  - Beam spread decreases as transducer frequency increases.
  - Beam spread decreases as transducer diameter increases.



Transducer FoV Example:



Accuracy for Multi-Object Detection



RESULTS

Reflected echoes overlap each other, which appears as one large object to the ultrasonic device.

Clear separation of the two echoes from the two different objects.

$$Resolution\ (m) = \frac{\#\ of\ Pulses}{frequency(Hz)} \times c$$

where c = *speed of sound*

To find more ultrasonic sensing technical resources and search products, visit ti.com/ultrasonic