AUTOMOTIVE ENVIRONMENT SENSORS

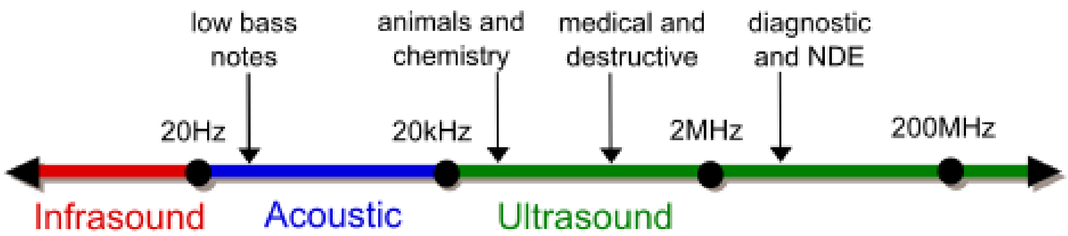
Lecture 11

Ultrasonic sensors

Dr. Szilárd Aradi

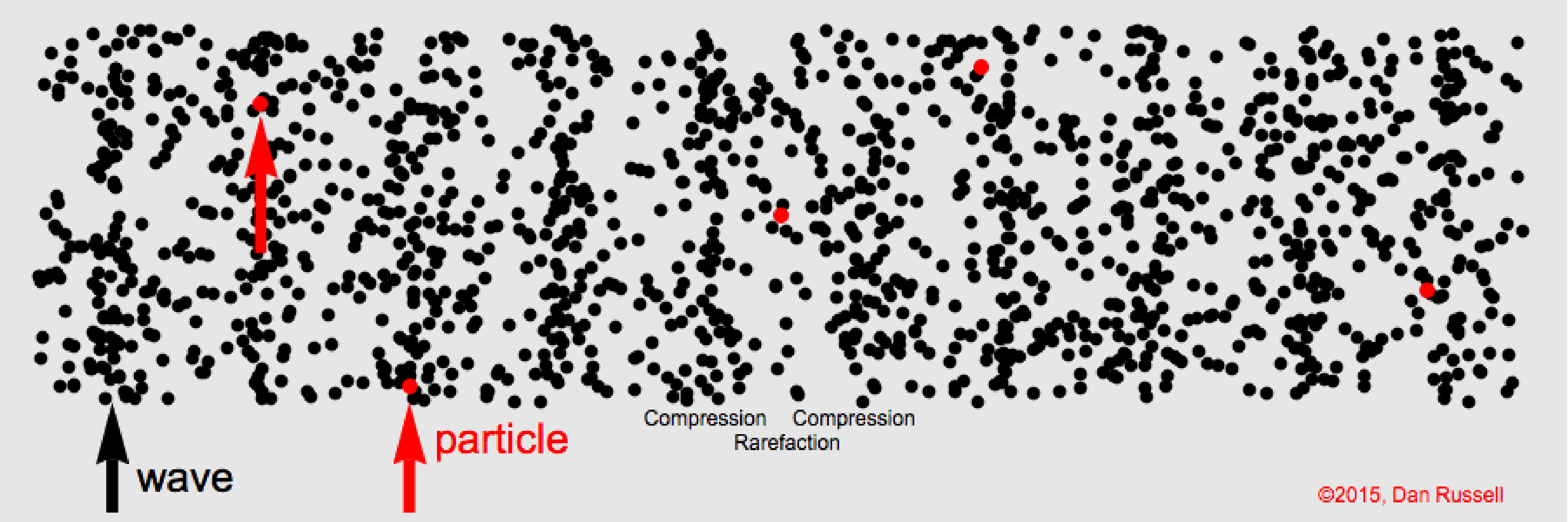
BME KÖZLEKEDÉSMÉRNÖKI ÉS JÁRMŰMÉRNÖKI KAR
32708-2/2017/INTFIN SZÁMÚ EMMI ÁLTAL TÁMOGATOTT TANANYAG

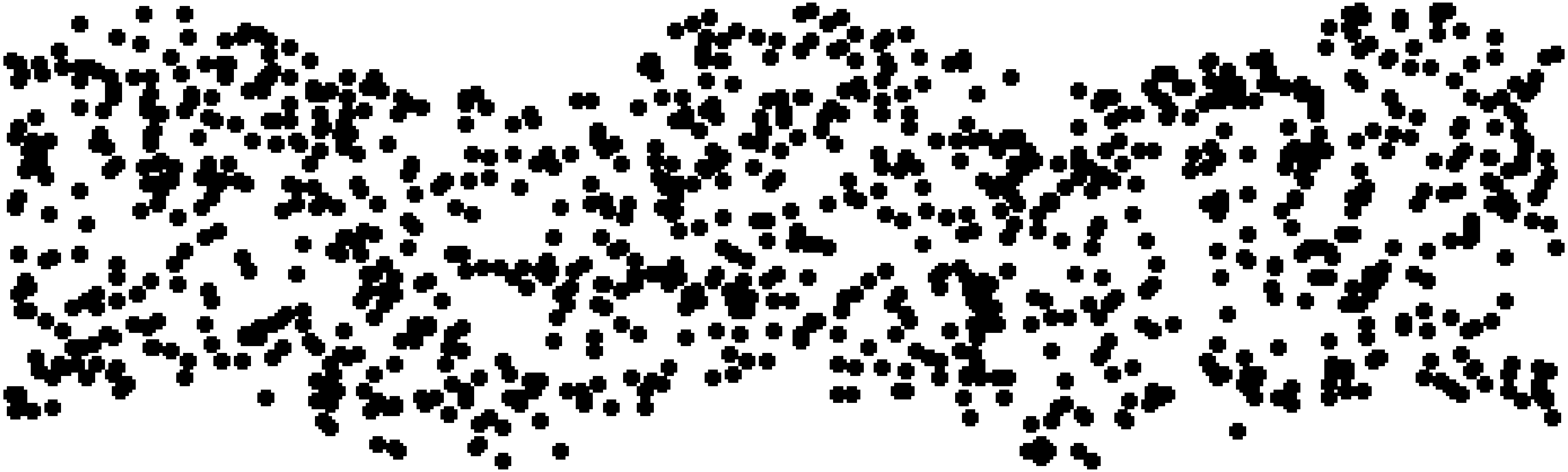
Ultrasonic sensing history



- Echolocation in bats was discovered by Lazzaro Spallanzani in 1794.
- Francis Galton in 1893 invented the Galton whistle, an adjustable whistle which produced ultrasound, which he used to measure the hearing range of humans and other animals, demonstrating that many animals could hear sounds above the hearing range of humans.
- The first technological application of ultrasound was an attempt to detect submarines by Paul Langevin in 1917.
- First experiments in the vehicle industry started in the 70s.
- Less sensitive to disturbance and dirt than vision based systems.

Principles


Compression
Compression
Rarefaction
particle
wave
©2015, Dan Russell



Speed of sound

- The speed of sound depends on the medium the waves pass through and is a fundamental property of the material.
- The bulk modulus (K) of a substance is a measure of how resistant to compressibility that substance is. It is defined as the ratio of the infinitesimal pressure increase to the resulting relative decrease of the volume.

$$K = -V\frac{dP}{dV} = \rho\frac{dP}{d\rho}$$

- The speed of longitudinal waves (Newton-Laplace equation):

$$c = \sqrt{K/\rho}$$

- From application aspects, the more important thing is that these properties change depending on the temperature. Speed in air at 0 °C is 331.45 m/s, changing:

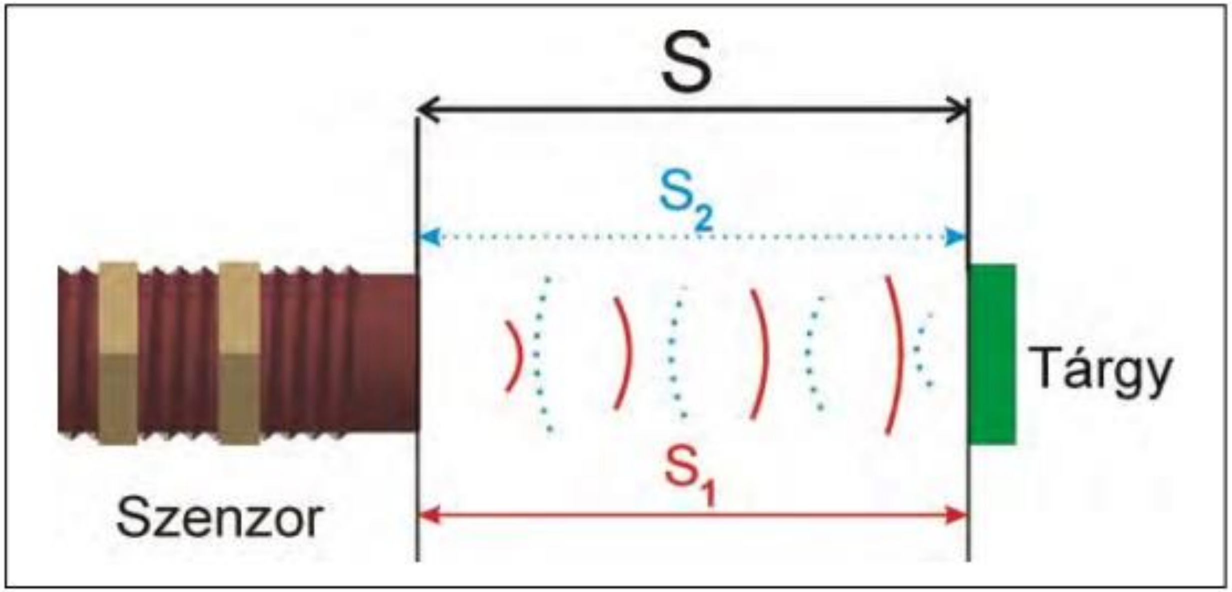
$$c(t) = c_0 + kt$$

$$k = 0.607\frac{m}{s \cdot {}^{\circ}C}$$

Distance calculation

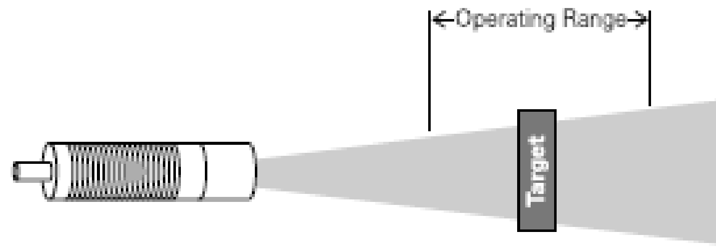
- Distance is measured as a function of the time between the emitting and receiving of the signal.

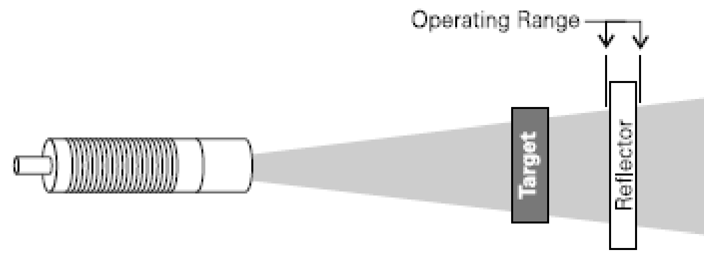
$$s = \frac{c \cdot t}{2}$$

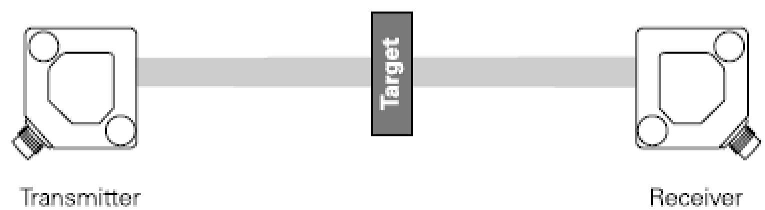


Operational modes

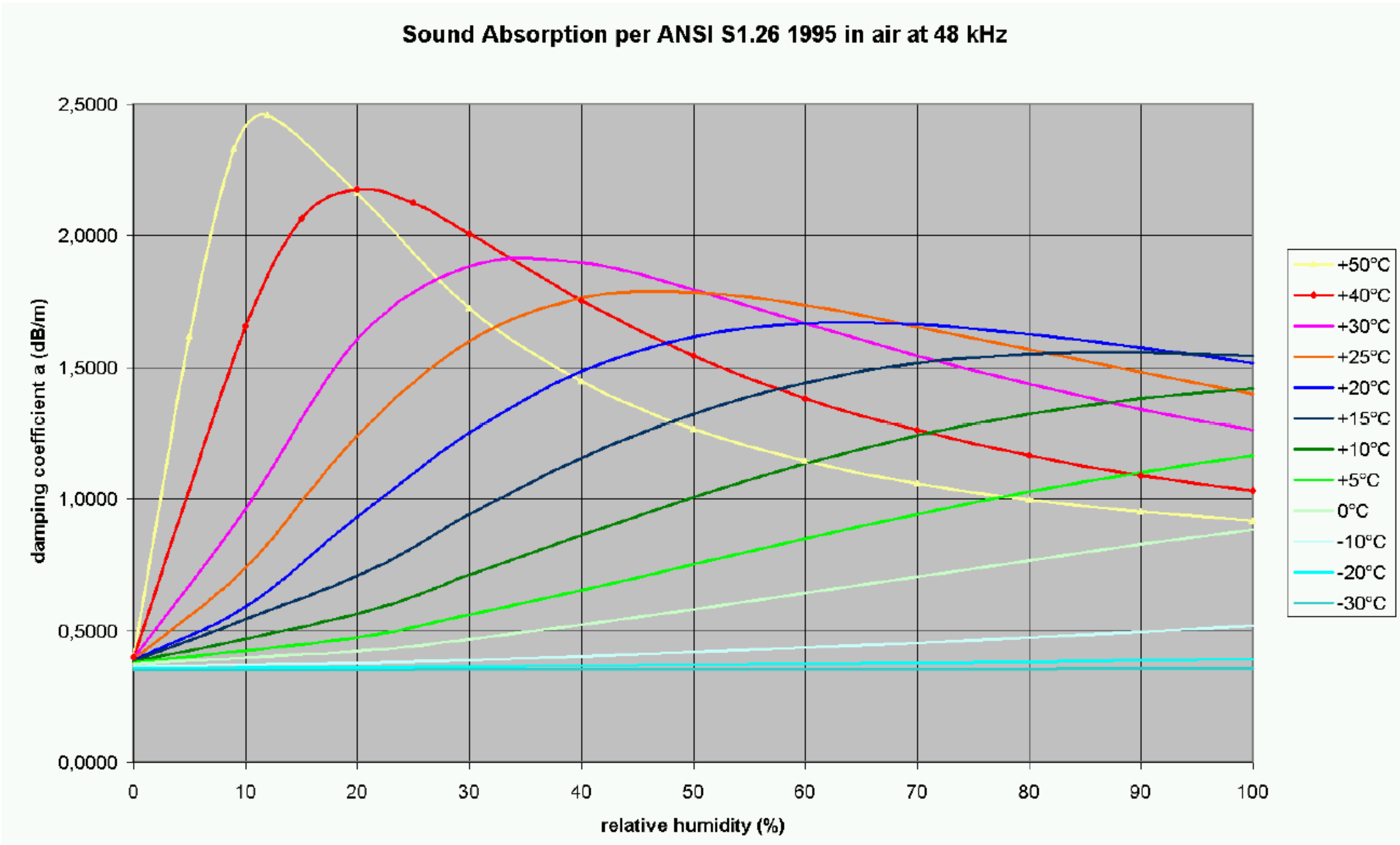
- Diffusion mode
  - The emitted signal reflects from the target
- Reflection mode
  - A reflector is placed within the operating distance, the target distracts the reflected signal.
- Gate mode
  - The emitter and the receiver is separated, the target object cuts the link between them.







48 kHz ultrasound absorption in air



Environmental effects

- **Temperature**: $c(t) = 331{,}45 + kt\left[\frac{m}{s}\right];\ k = 0.607\,\frac{m}{s\cdot °C}$
- **Humidity:** see previous slide
- **Wind:**
  - <50km/h – No problem
  - 50-100 km/h – Uncertain result
  - >100km/h – No reflection.

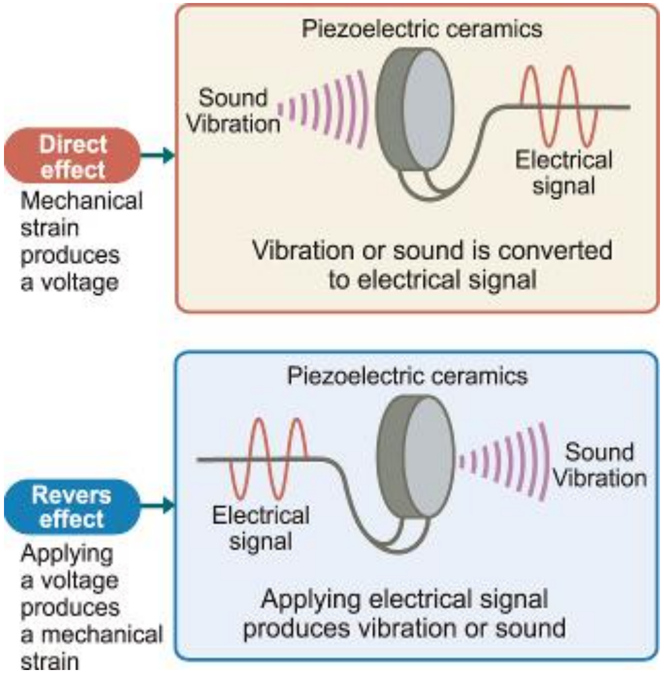
- **Medium:** The sensors are designed for air. (There is no sound in vacuum)
- **Rain, snow:** „Normal” weather does not affect.
- **Dust, ice:** Can reduce effective distance with 67-75%.

Effective distance

- Maximal distance in practice is **~5-6m**. Absorption mainly depends on frequency (and afterwards temperature and humidity). Sensor are calibrated at 25 °C, 45% humidity and 94.48 kPa pressure. (Speed is compensated by temperature, as previously mentioned)
- Shortest measurable distance („blind zone”) is around **~20 cm**. This is limited by the switching time between emitting and receiving the echo.

Generating ultrasound

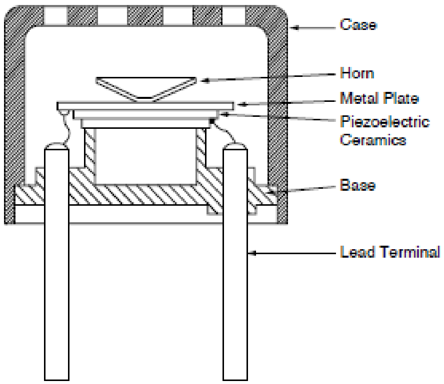
- In the vehicle industry, ultrasound is transmitted and received by sensors using piezoelectricity.
- The piezoelectric effect is a **reversible** process in that materials exhibiting the **direct piezoelectric effect** (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the **reverse piezoelectric effect** (the internal generation of a mechanical strain resulting from an applied electrical field).



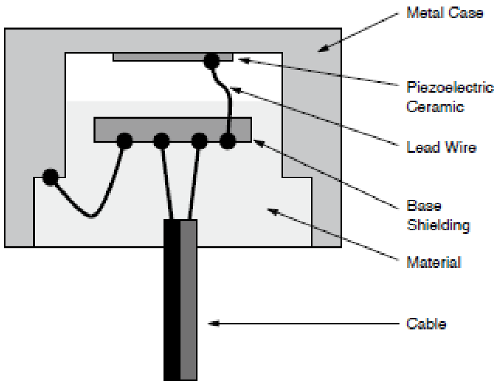
Sensor architecture

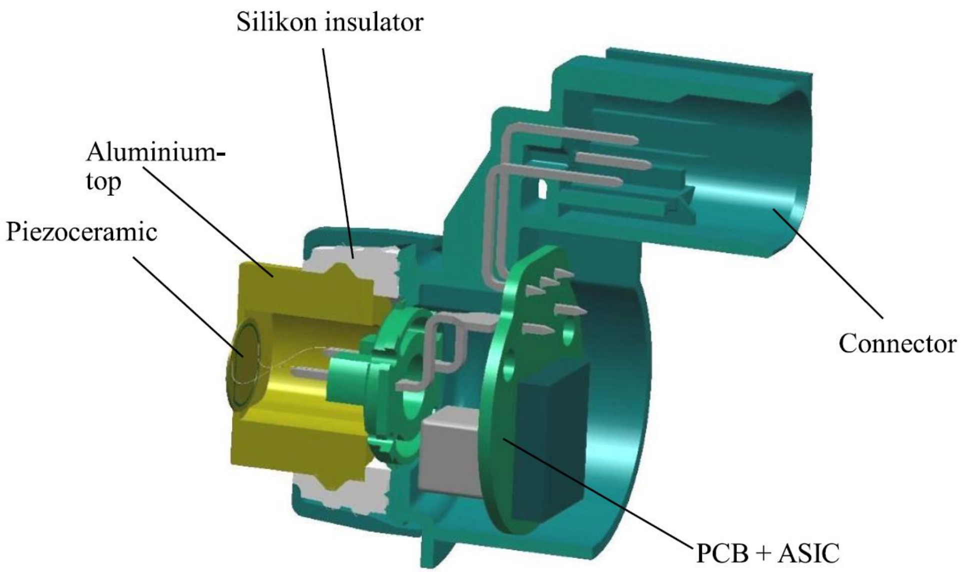
- **Case:** protects the PE ceramic at open structure, holds the PE at closed structure.
- **PE ceramic:** Converts ultrasound to and from electric signal.
- **Horn:** Used with open architecture, concentrates waves to the PE.
- **Base**
- **Insulation**
- **Wires**

Open

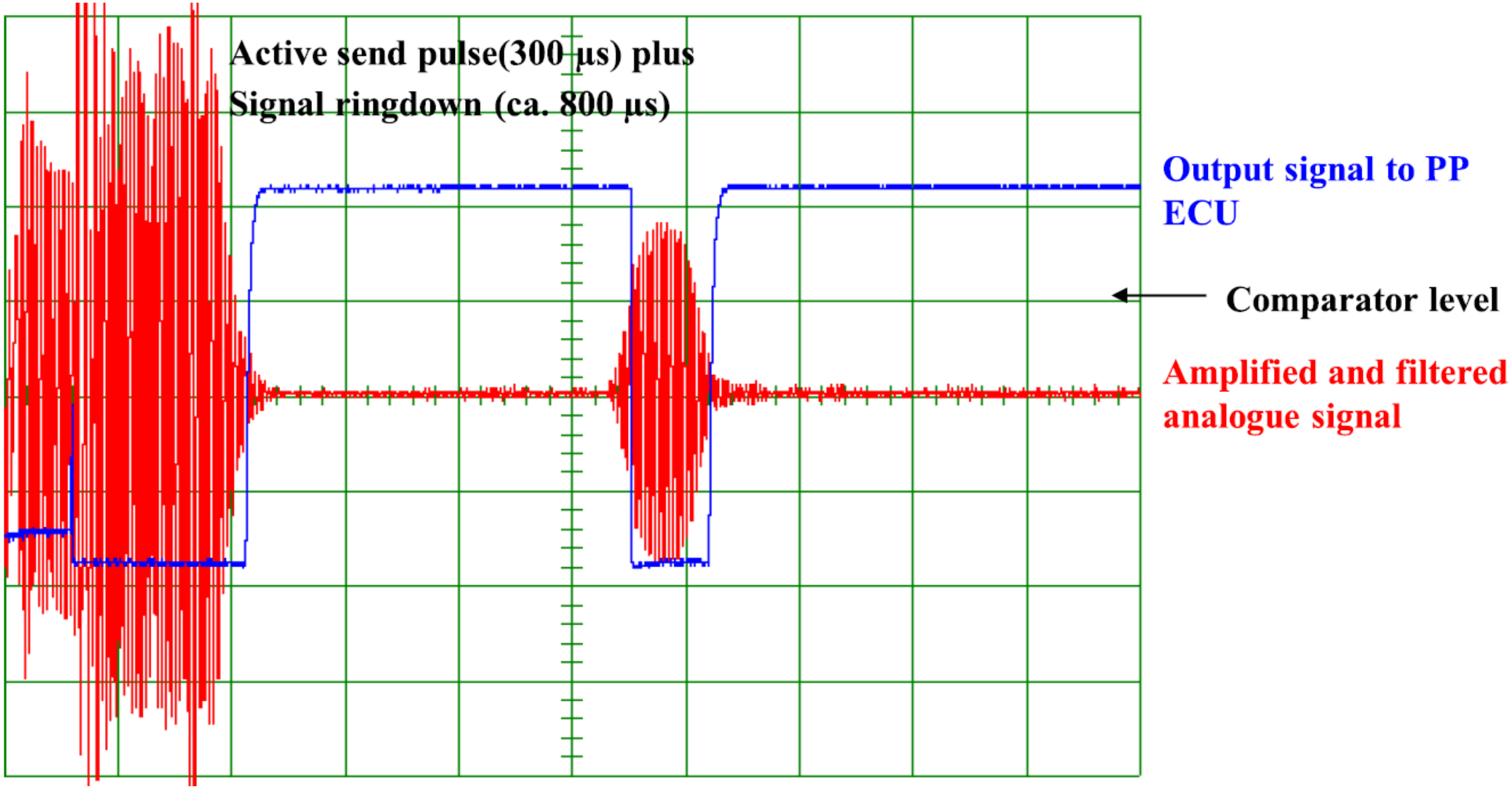


Closed



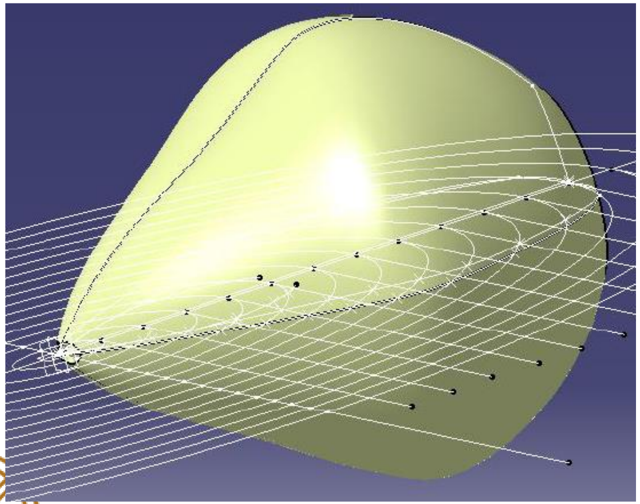


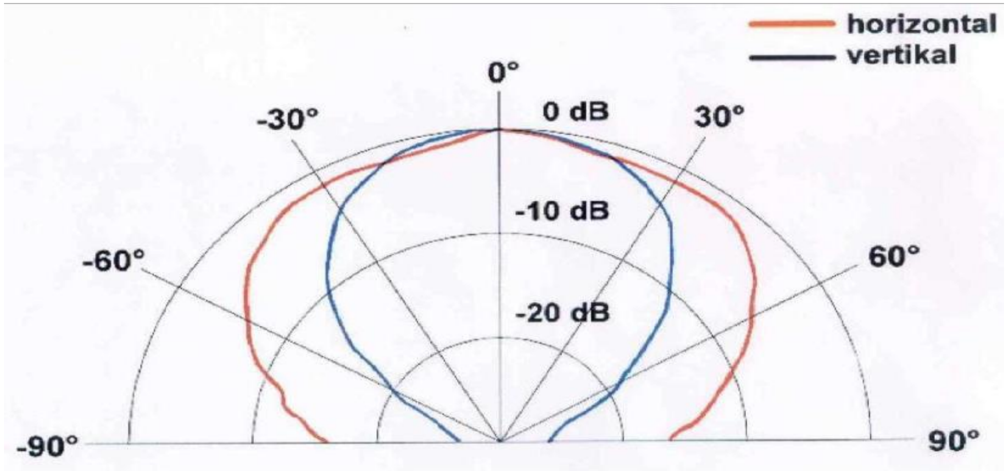
Distance measurement



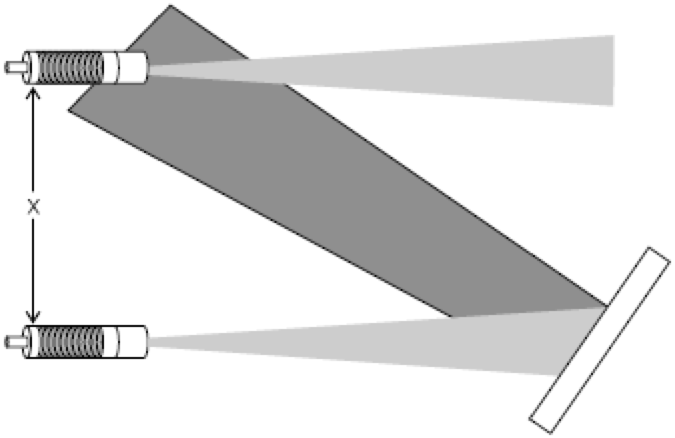
Ultrasonic sound cone

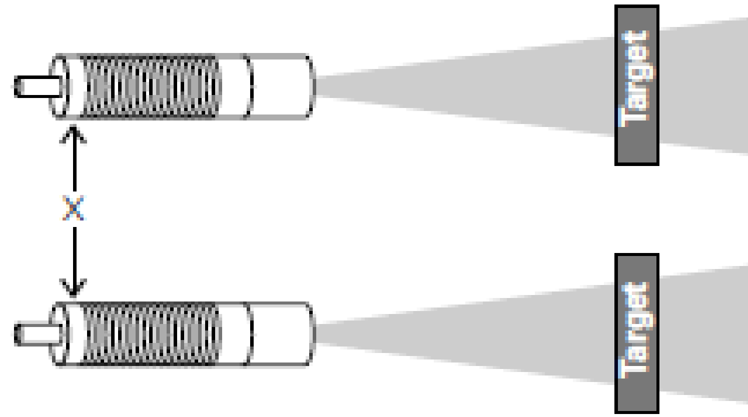
- Emitted ultrasound spreads in a cone.
- The figure below shows the characteristics of a Bosch sensor.





Cross-echo

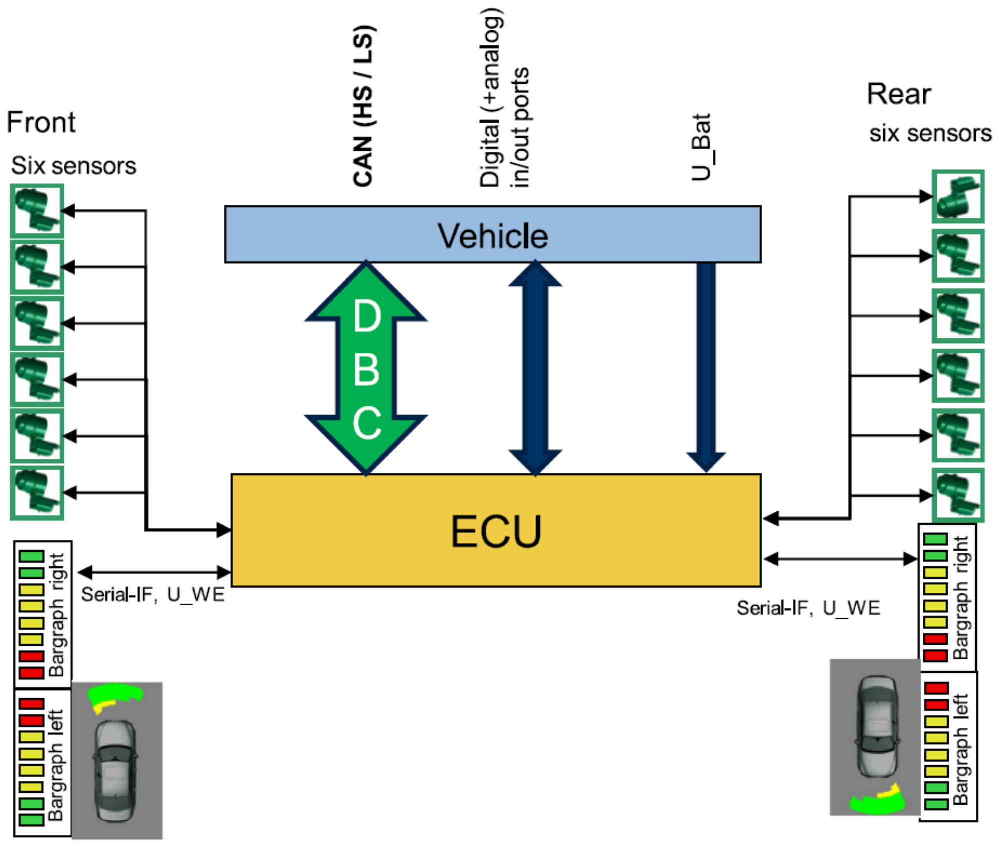




- Emitting cones of neighboring sensors may overlap.
- The ultrasound generated by one sensor can stimulate its neighbor also. („cross-echo”).
- For simple distance measurements, these sensors are used separately in a predefined order.
- On the other hand, cross echo can be used with triangulation for more accurate measurements.

Architecture

- Inputs
  - Ignition
  - Gear
  - Speed
  - Temperature
  - etc.
- Outputs
  - Raw distances
  - Measurement verification
  - Object Distances
  - etc.



BUDAPESTI MŰSZAKI ÉS GAZDASÁGTUDOMÁNYI EGYETEM

Dr. Szilárd Aradi

email: aradi.szilard@mail.bme.hu

MŰEGYETEM 1782

Thank you for your attention!