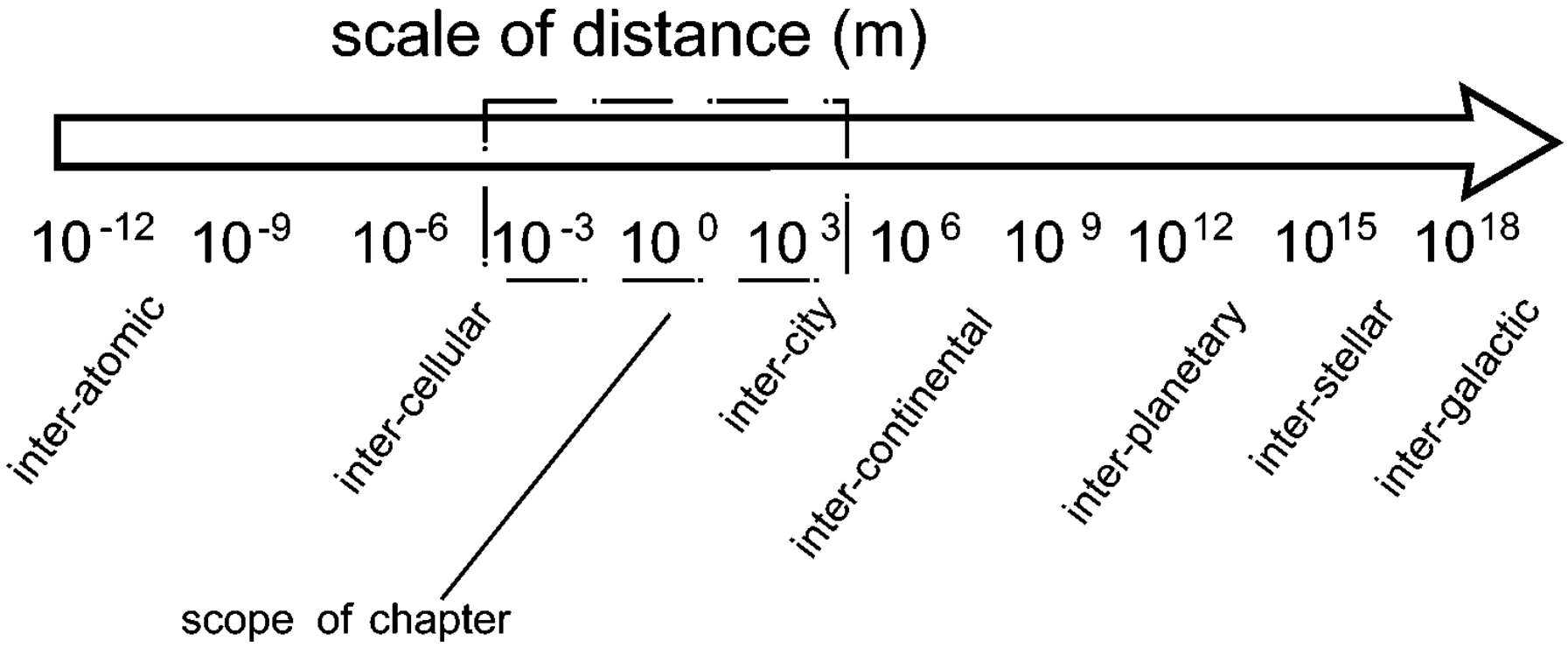
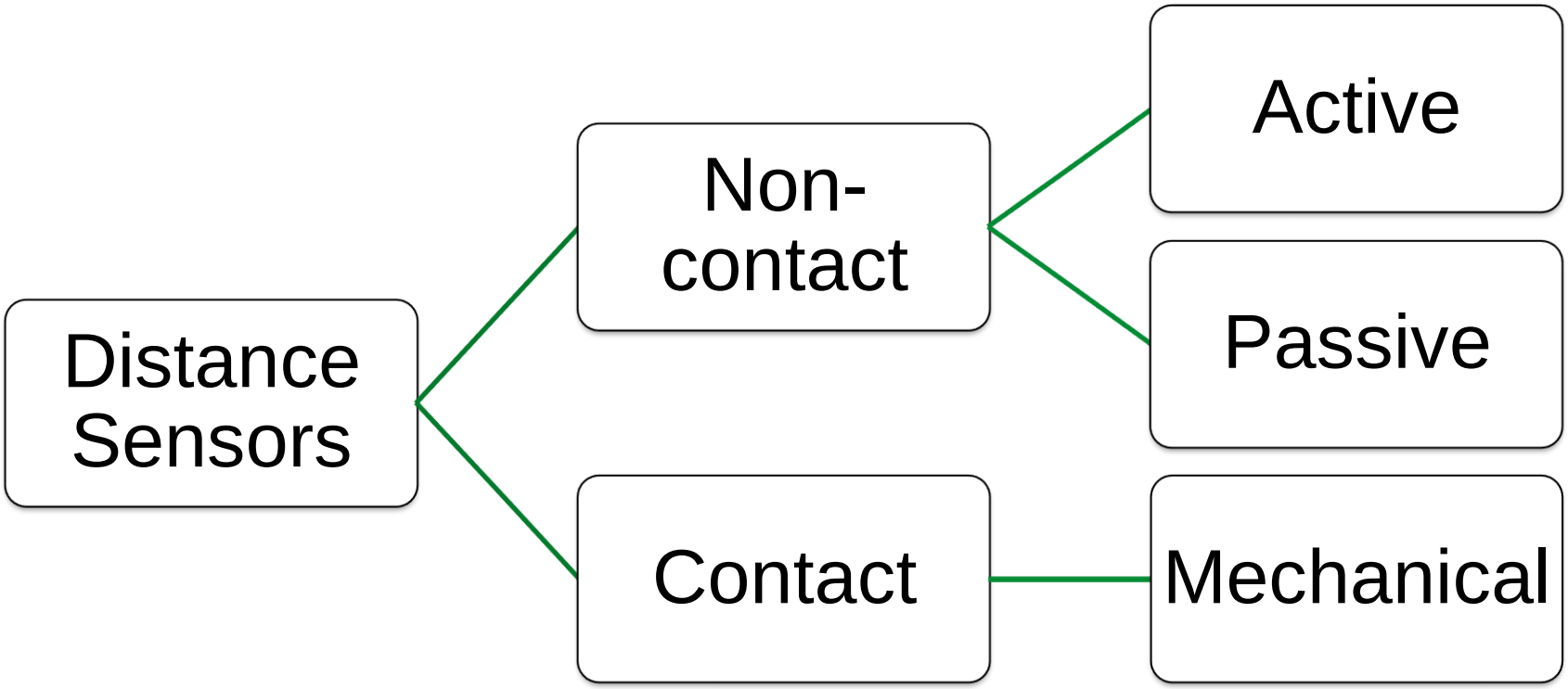
Aalto-yliopisto
Sähkötekniikan
korkeakoulu

Distance and Velocity

ELEC-E5710 Sensors and Measurement Methods

Distance Sensors



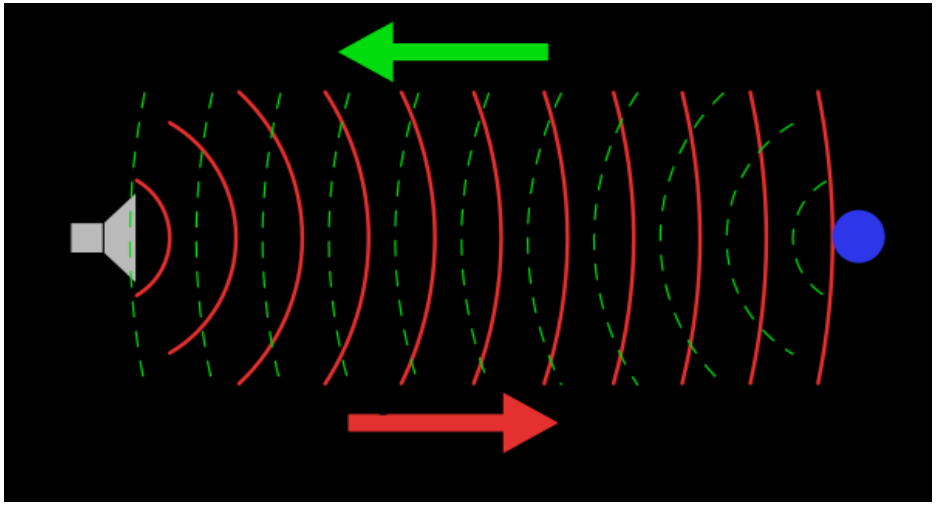

Distance Sensors
Non-contact
Contact
Active
Passive
Mechanical

Distance Sensors

- Limit Switches
- Ultrasonic sensor
- Proximity sensors
- Optical Encoders
- **SONAR**
- **RADAR**
- **LIDAR**

SONAR

- Sound Navigation Ranging
- *passive* sonar is essentially listening for the sound made by vessels; *active* sonar is emitting pulses of sounds and listening for echoes.
- used as a means of acoustic location and of measurement of the echo characteristics of "targets" in the water.



ACTIVE SONAR

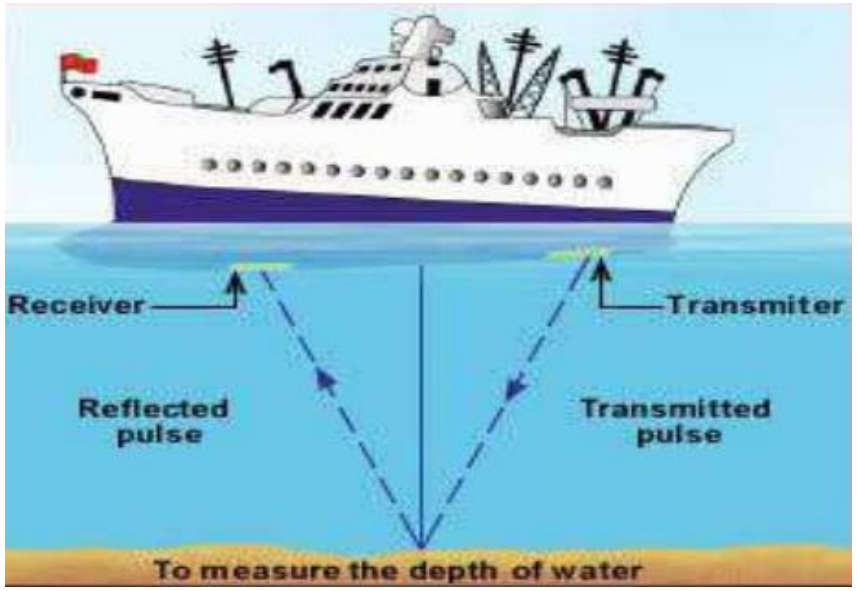
Active sonar uses a sound transmitter and a receiver.

- When the two are in the same place it is **monostatic operation**.
- When the transmitter and receiver are separated it is **bistatic operation**.
- When more transmitters (or more receivers) are used, again spatially separated, it is **multistatic operation**.

Active sonar creates a pulse of sound, often called a "ping", and then listens for reflections (echo) of the pulse.

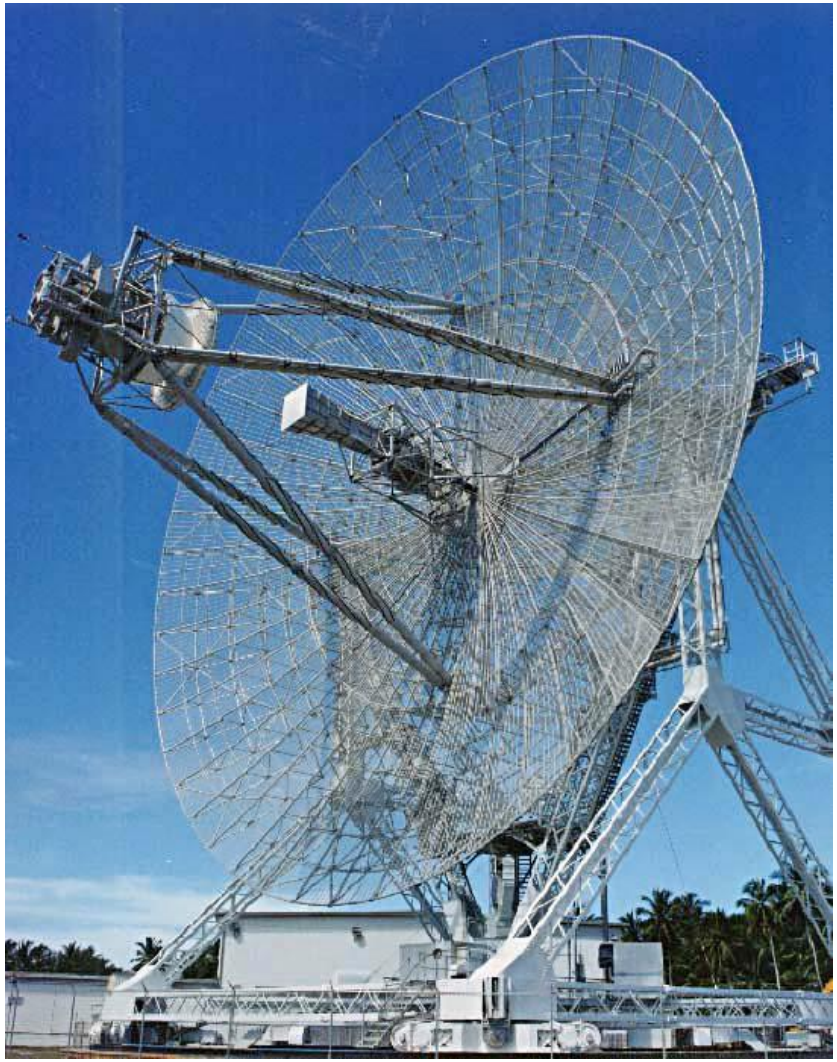
SONAR

- The first recorded use of the technique was by Leonardo da Vinci in 1490 who used a tube inserted into the water to detect vessels by ear.
- Special short range sonars have been developed to allow measurements of water velocity.



Radar (Radio Detection And Ranging)

- Radar is a detection system that uses radio waves to determine the range, angle, or velocity of objects.
- A radar system consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, a transmitting antenna, a receiving antenna and a receiver and processor to determine properties of the object.



Radar

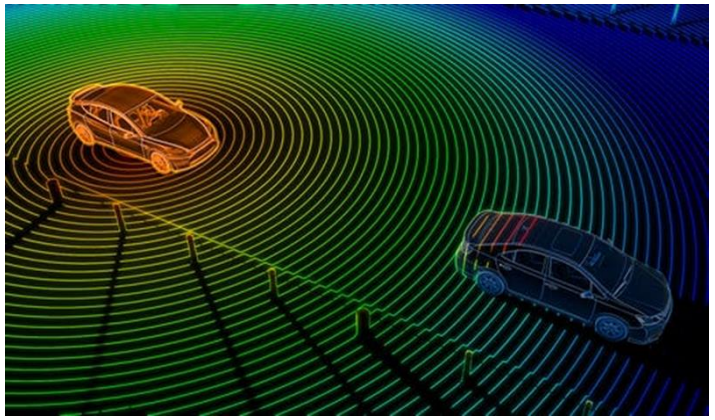
The information provided by radar includes the bearing and range of the object from the radar scanner.

In aviation, aircraft can be equipped with radar devices that warn of aircraft or other obstacles in or approaching their path, display weather information, and give accurate altitude readings.

Marine radars are used to measure the bearing and distance of ships to prevent collision with other ships

LIDAR

- Light Detection And Ranging
- a method for measuring distances (ranging) by illuminating the target with laser light and measuring the reflection with a sensor
- LIDAR consists of:



Laser: 300 nm – 1200 nm

Scanner and Optics

Photodetector and receiver electronics (solid state photodetectors or photomultipliers)

Position and navigation systems (GPS or IMU)

LIDAR

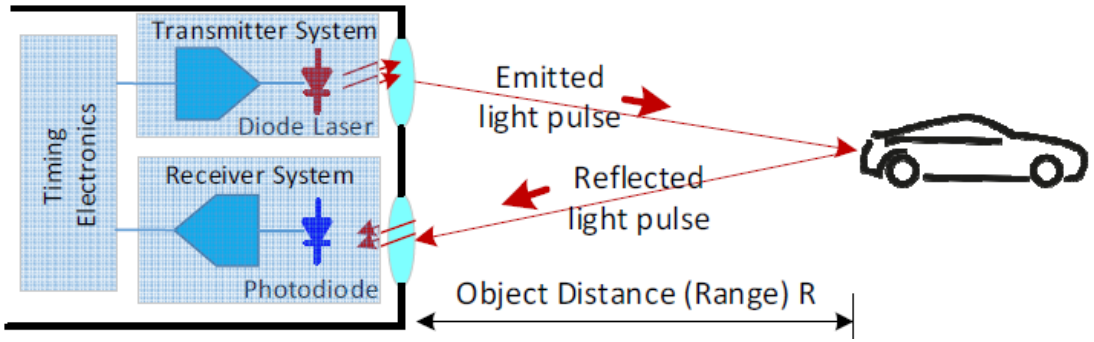
two kinds of lidar detection scheme:

- "incoherent" or direct energy detection (which principally measures amplitude changes of the reflected light)
- coherent detection (best for measuring Doppler shifts, or changes in phase of the reflected light)

Both types employ pulse models: either micropulse or high energy.

LIDAR

- NASA's Apollo 15 used laser retroreflector it to map the moon
- 2005 used with cars by Toyota Tundra.
- Autonomous cars: information by LIDAR allows the construction of a comprehensive 3D map of the vehicle environment and a classification of the objects within it (upto 200 m).



Ceilometer

- employs a pulsed diode laser LIDAR
- short, powerful laser pulses are sent out in a vertical or near-vertical direction
- reflection of light (backscatter) caused by clouds, precipitation or other obscuration is analyzed
- high-range cloud height detection
- Cloud reporting range up to 13 km
- Available at Vaisala Oy.

Velocity Sensors

- Electromagnetic Velocity Sensor

  Moving magnet type

  Moving coil type
- Seismic velocity transducers
- Linear velocity transducers
- SODAR
- Doppler Radar
- Laser Doppler Veocimtimeter
- Pitot
- Particle Image Velocitimeter
- Piezoelectric sensors

Electromagnetic Velocity Sensor

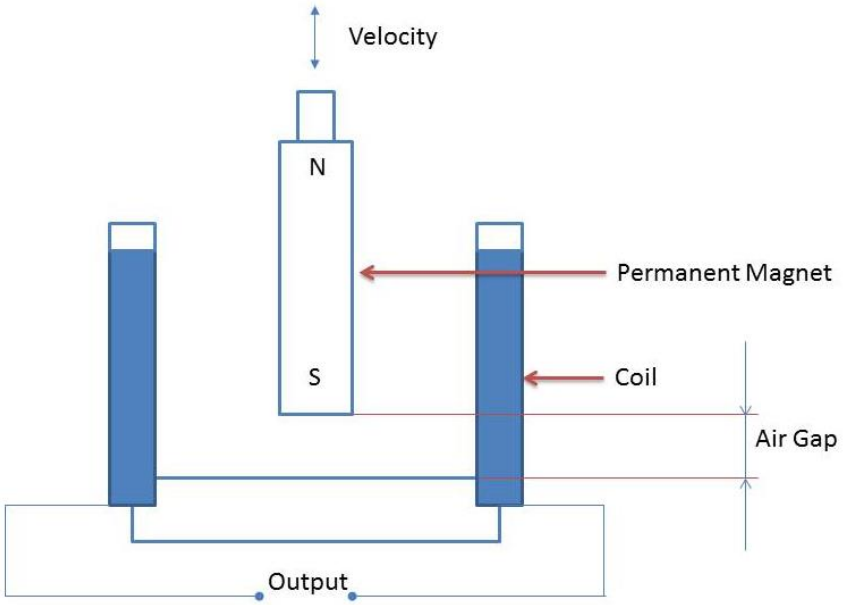
- For measurement of linear velocities
- Utilizes the voltage produced in a coil on account of change in flux linkages resulting from change in reluctance.

(a) Moving magnet type

(b) Moving coil type

Moving magnet type transducer

- Sensing element is a rod type permanent magnet that is rigidly coupled to the device whose velocity is being measured.
- Motion of magnet induces voltage in coil



- Amplitude of voltage directly proportional to the velocity
- Polarity of voltage determines the direction of motion

Application

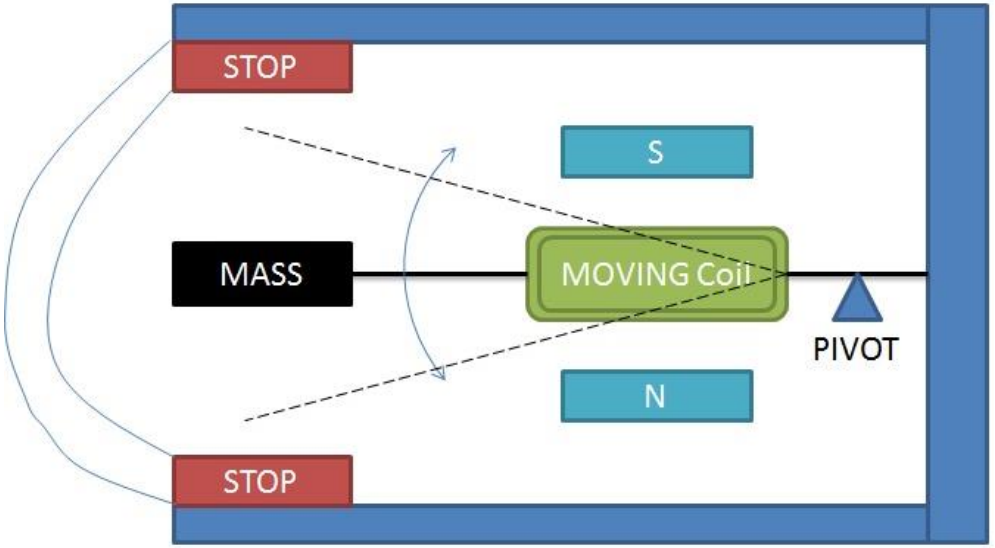
- Moving coil velocity transducers are commonly used in vibration monitoring applications.

Disadvantages:

- Adversely affected by stray magnetic fields
- Progressive demagnetization

Moving coil type transducers

- The antimagnetic case reduces the effects of stray magnetic field.
- Damping is obtained electrically.
- There is high stability under varying temperature conditions.

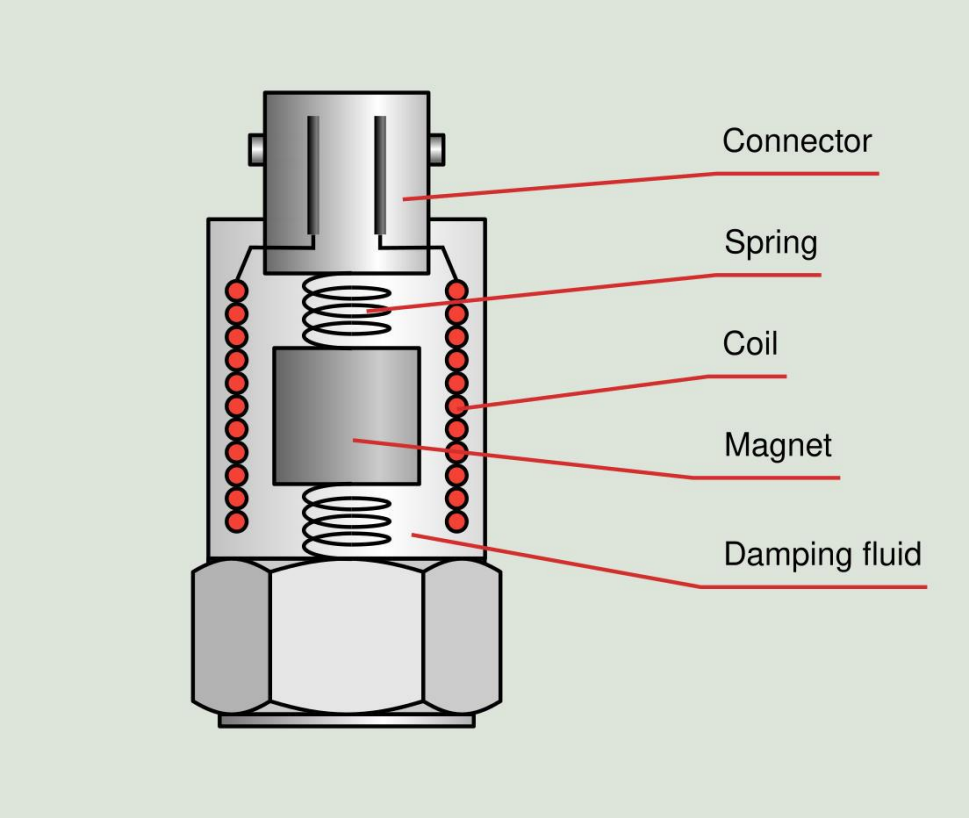


- These transducers are used for measuring velocities in linear, sinusoidal or random manner.

Seismic velocity transducers

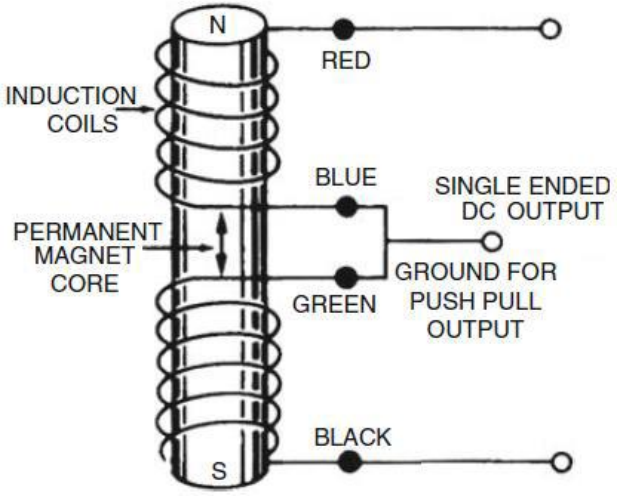
A permanent magnet is supported between two springs and fitted with low friction bearing rings.

Seismic vibration monitoring applications:
Vibrations in buildings, bridges etc.
Sensitive and high resolution



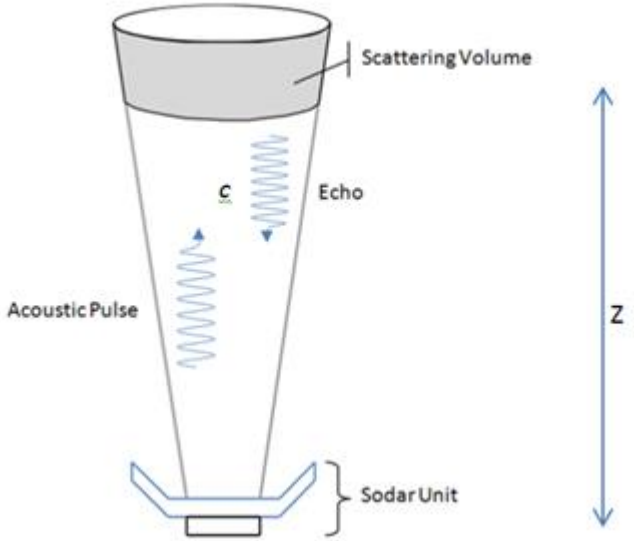
Linear velocity transducer

- A linear velocity transducer (LVT) is an inductive device that is similar in principle to the linear variable displacement transducer (LVDT) discussed previously.
- Whereas an LVDT measures displacement, an LVT measures speed.
- In 2008, two students, James Weyand and Collin Julius from Penn state university, used a velocity coil to measure the muzzle speed of an air cannon



SODAR

- Sound Detection And Ranging
- meteorological instrument used as a wind profiler
- used to measure wind speed at various heights above the ground



Doppler SODAR

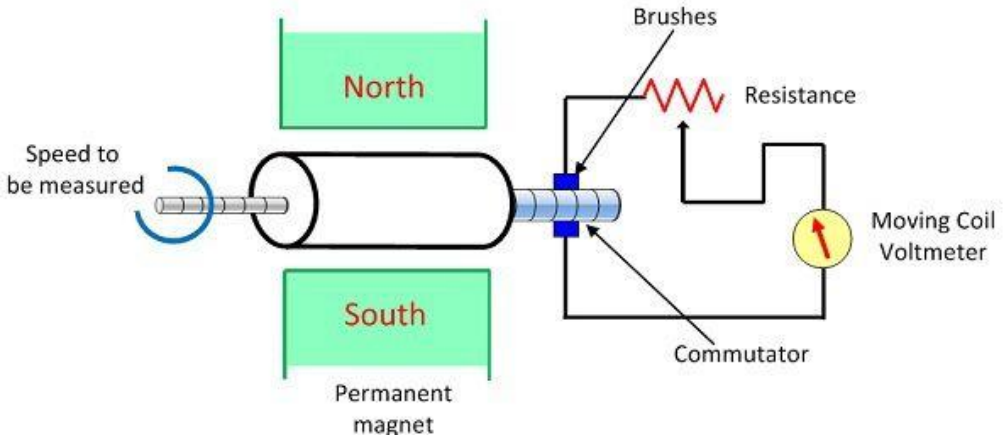
Mono-static antenna systems can be divided into two categories:

- those using multiple axis, individual antennas
- those using a single phased array antenna

Applications:

- used for wind power applications
- accurate estimate of wind flow and therefore energy production of a wind turbine

Tachometer



- Used to measure the angular velocity of vibrating objects.
- They provide an output voltage/frequency that is proportional to the angular velocity.
- DC tachometers use a permanent magnet or magneto, while the AC tachometers operate as avaliable coupling transformer, with the coupling coefficient proportional to the rotary speed

Doppler Radar

- Doppler radar is a specialized radar that uses the Doppler effect to produce velocity data about objects at a distance.
- There are four ways of producing the Doppler effect. Radars may be:

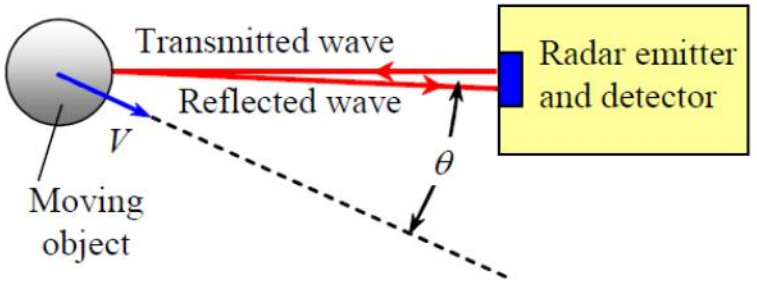
  Coherent pulsed (CP),

  Pulse-Doppler radar,

  Continuous wave (CW), or

  Frequency modulation (FM).

Doppler Radar



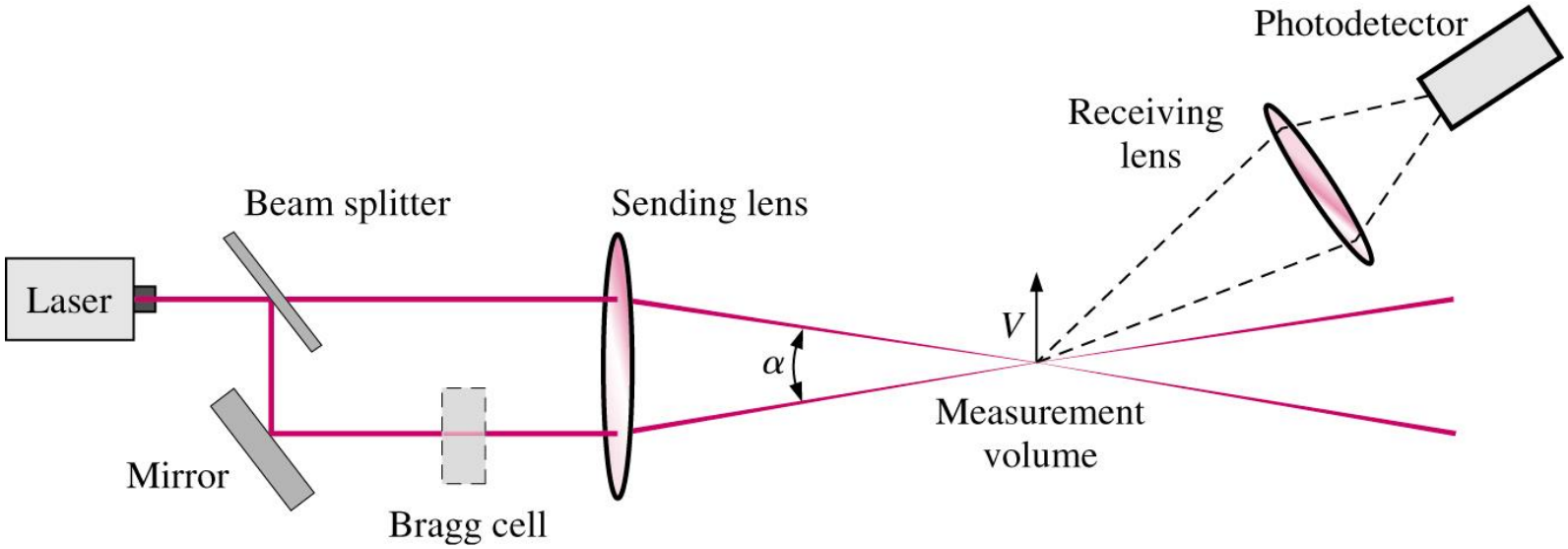
Working principle of radar velocitimeter:

- Radio waves are transmitted and incident towards moving object
- Object moves with velocity V and angle theta
- Waves reflect off moving object and are sensed by a detector
- Detector measures the frequency of the reflected beam
- The unit compares the frequency of the transmitted and reflected beams

Doppler Radar

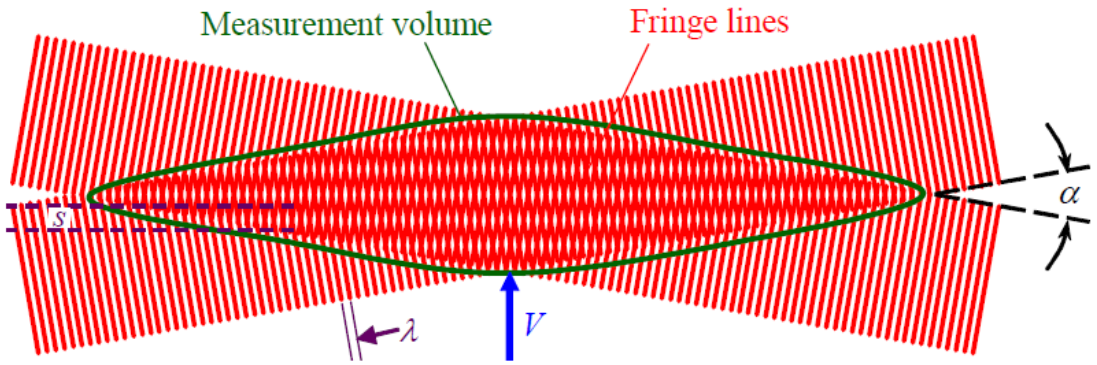
- Doppler radars were used as a navigation aid for aircraft and spacecraft. By directly measuring the movement of the ground with the radar, and then comparing this to the airspeed returned from the aircraft instruments, the wind speed could be accurately determined.
- Pulse-Doppler radars combine all the benefits of long range and high velocity capability. Pulse-Doppler radars use a medium to high PRF (on the order of 3 to 30 kHz), which allows for the detection of either high-speed targets or high-resolution velocity measurements.

Laser Doppler velocimetry



LDV is used to measure the velocity of particles in the fluid

Laser Doppler velocimetry



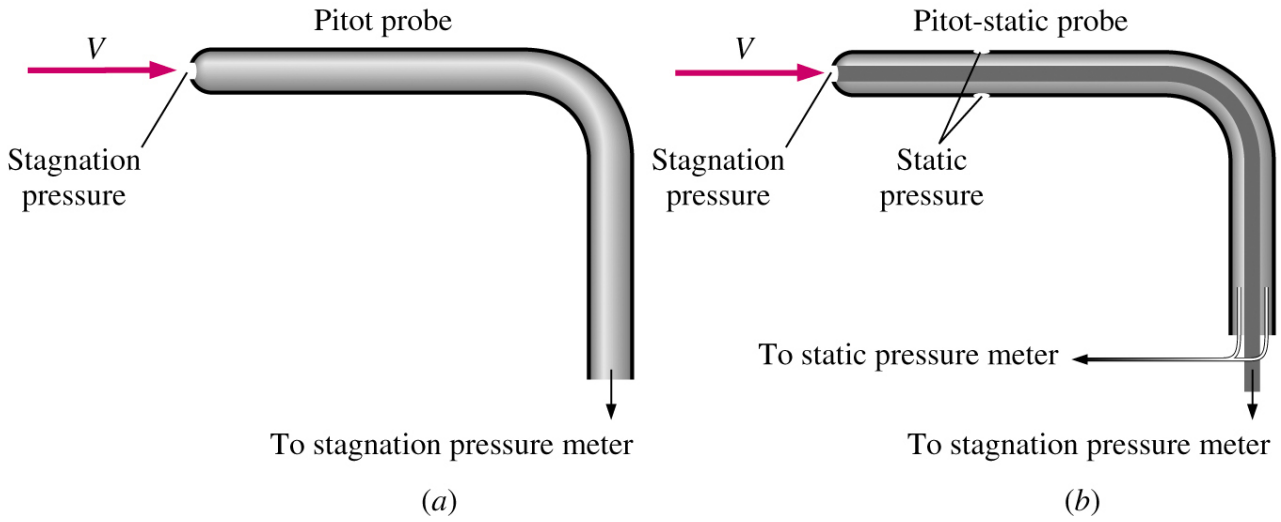
$$V = fs = \frac{f\lambda}{2\sin\left(\frac{\alpha}{2}\right)}$$

$$s = \frac{\lambda}{2\sin\left(\frac{\alpha}{2}\right)}$$

$$\Delta f_D = \frac{2V\cos\theta}{\lambda}$$

Pitot and Pitot-static probes

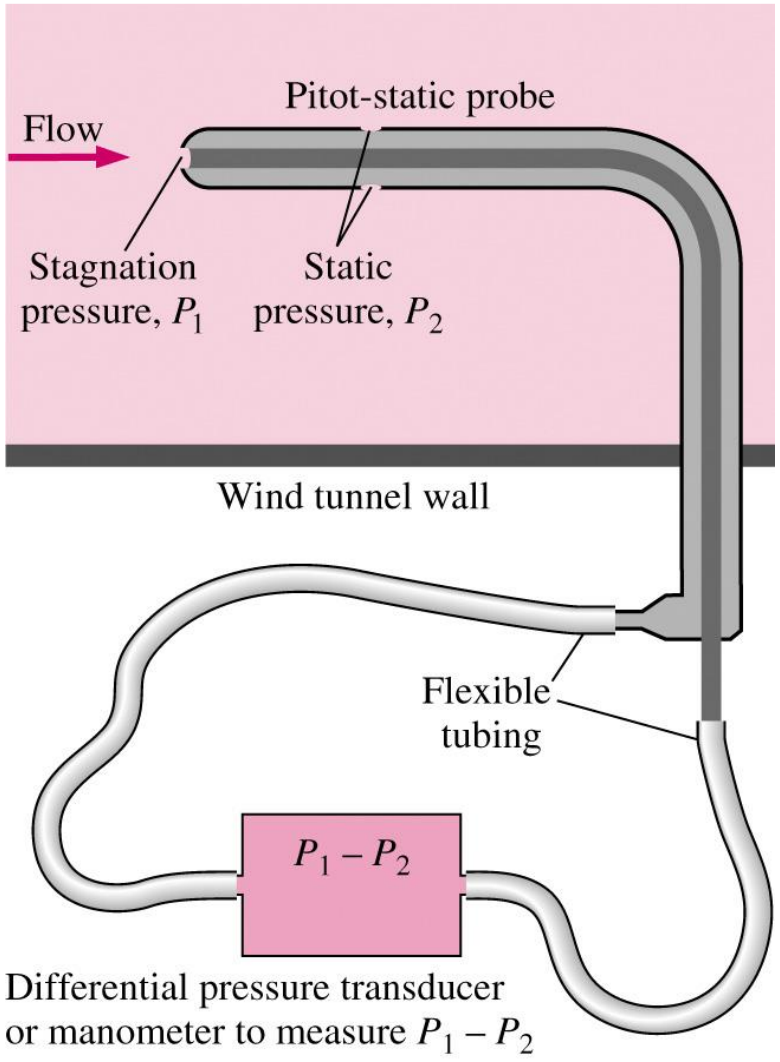
- A Pitot probe is just a tube with a pressure tap at the stagnation point that measures stagnation pressure.
- A Pitot-static probe has both a stagnation pressure tap and several circumferential static pressure taps, and it measures both stagnation and static pressures.



Pitot and Pitot-static probes

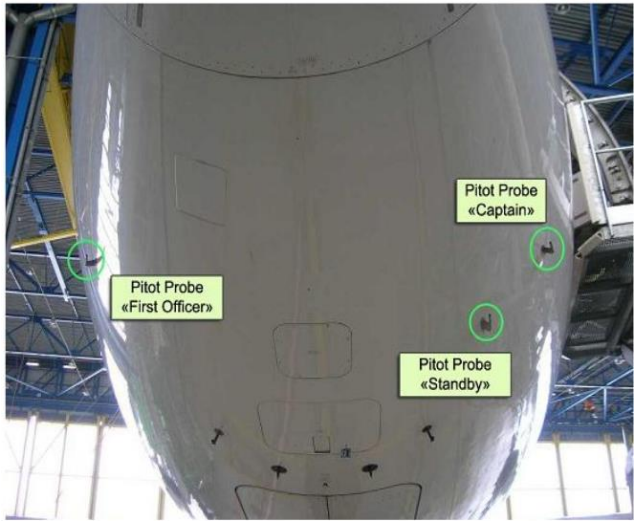
Applications:

- measurement of velocity in a wind tunnel
- In airplanes, under the wing or on the fuselage
- measure fire hydrant velocity



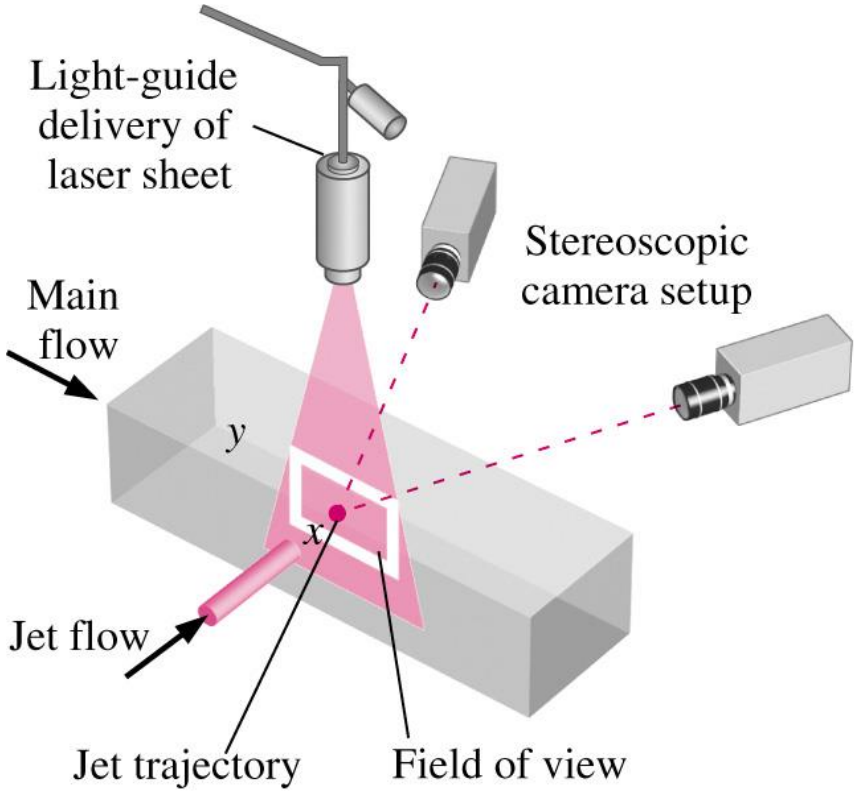
Pitot accident

- The aircraft departed from Rio De Janeiro to Paris.
- The aircraft had three pitot tubes to measure velocity
- Icing on one of the pitot tubes
- Different velocity readings from the three tubes



Particle Image Velocimetry

- The fluid is seeded with tiny particles that are so small that they move with the fluid.
- A double-pulse laser illuminates a region of flow under study, and a digital camera (sometimes two separate cameras) records two images – timed with the two flashes (pulses) of laser light. Illuminated particles appear as bright spots on the photographs because of the flashes of laser light.
- The displacement of illuminated particles is then determined by analyzing (interrogating) the two digital photographs with sophisticated image processing software



Particle Image Velocimetry

There are two basic types of PIV:

- Standard PIV (two rapid laser flashes with a very small Δt followed by a long pause before the next series of laser flashes)
- Cinema or cinemagraphic PIV (one laser flash per camera frame with There are both 2-D and 3-D PIV systems:

There are both 2-D and 3-D PIV systems:

- 2-D systems use one camera and measure flow velocity in a plane illuminated by a laser light sheet, as shown here (from Georgia Tech).
- 3-D systems use two cameras (stereoscopic photography) to measure the velocity in the plane of the laser light sheet, and also in the directionno pause, like a video or movie, but typically a longer Δt)

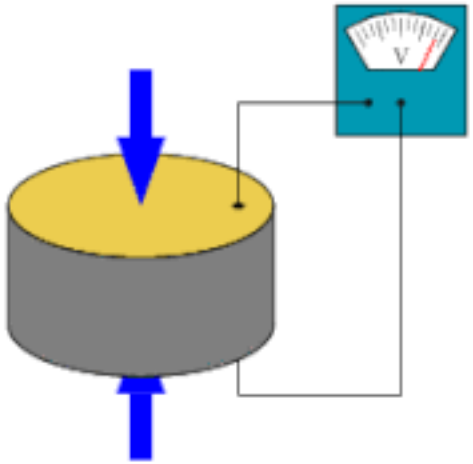
Piezoelectric Sensor

- Cut of piezoelectric material produces three main operational modes:

  1) Transvers

  2) Longitudinal

  3) Shear



Two main groups of materials are used: piezoelectric ceramics and single crystal materials.

Questions

- Don is driving 67.0 mph in a 55 mph zone. A police officer nails him with a radar gun that uses a frequency of 10,000 MHz. Angle θ is 10^0 at the moment of the reading. Calculate the Doppler frequency shift.
- Pitot static tube is mounted on an aircraft travelling at a speed 300kmph against a wind velocity of 20 kmph. If the specific weight of air is 12 N/m3 determine the pressure difference the instrument will register.

Questions

- In the dry air at 20°C (68°F), the speed of sound is 343.2 meters per second. The sound wave is emitted by the sensor and travels to the object, bounces off and travels back to the sensor. The time that it takes for a sound wave to come back to the sensor is recorded and given to the user. If the round-trip travel time of the sound wave is $3*10-3$ seconds, what is the distance between the sensor and the object?
- In your opinion, what could have done to avoid the airplane crash mentioned earlier?