Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-9: Motion and Sound Sensors

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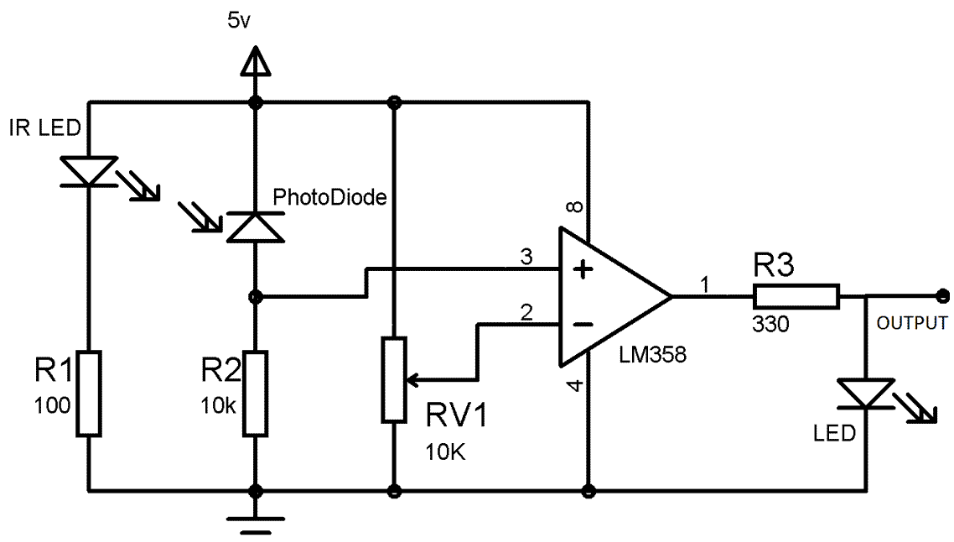
Motion Sensors

Motion sensors are devices that detect movement or changes in their immediate environment and trigger a response based on this detection. There are several types of motion sensors, each with its own working principle and applications.

Passive IR sensor

A passive infrared (PIR) sensor circuit typically uses a pair of pyroelectric sensors, also known as pyroelectric detectors or PIR sensors, to detect changes in infrared radiation emitted by objects in their field of view.



Components:

- **Vcc:** This is the power supply voltage. It is typically in the range of 3-5 volts, depending on the PIR sensor model.
- **Signal Output:** This is the sensor's output pin, which provides a digital signal when motion is detected. When motion is detected, it goes high (logical 1); otherwise, it remains low (logical 0).
- **R1:** This is a pull-up resistor connected between Vcc and the Signal Output. It is typically around 10K ohms and is used to ensure a stable logic level when motion is not detected.
- **PIR Sensor:** The PIR sensor itself is a small device that contains two pyroelectric sensors facing in different directions. When an object moves in front of the sensor, it generates a change in the infrared radiation that is detected by the pyroelectric sensors.
- **R2:** This is an optional resistor that can be used to adjust the sensitivity or trigger delay of the PIR sensor. It is not always present in every PIR sensor circuit.

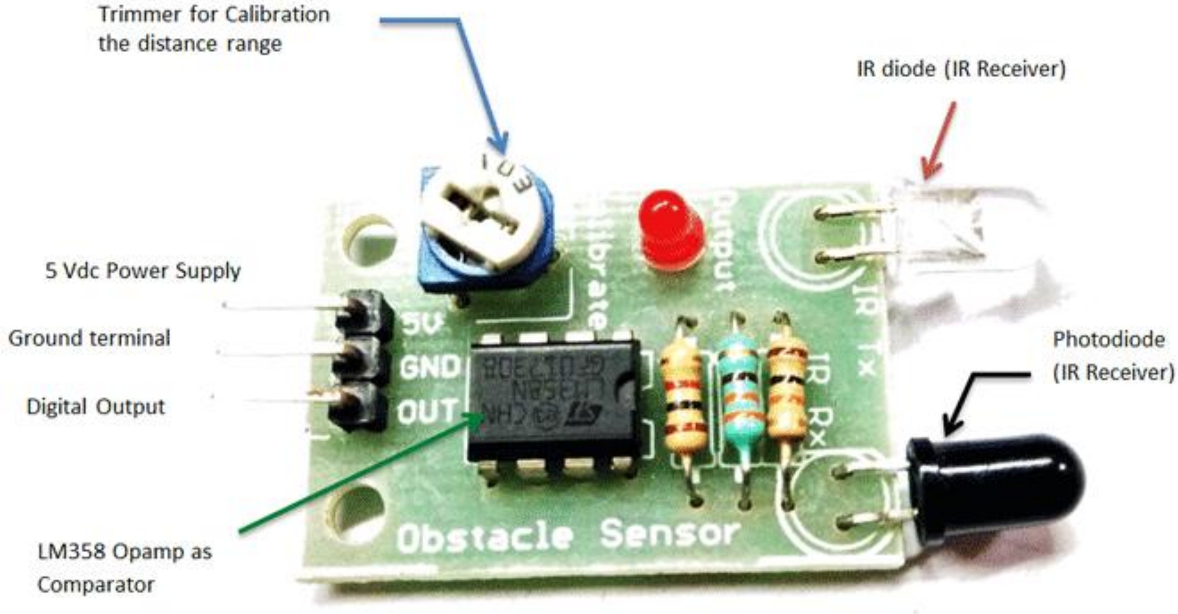
Operation:

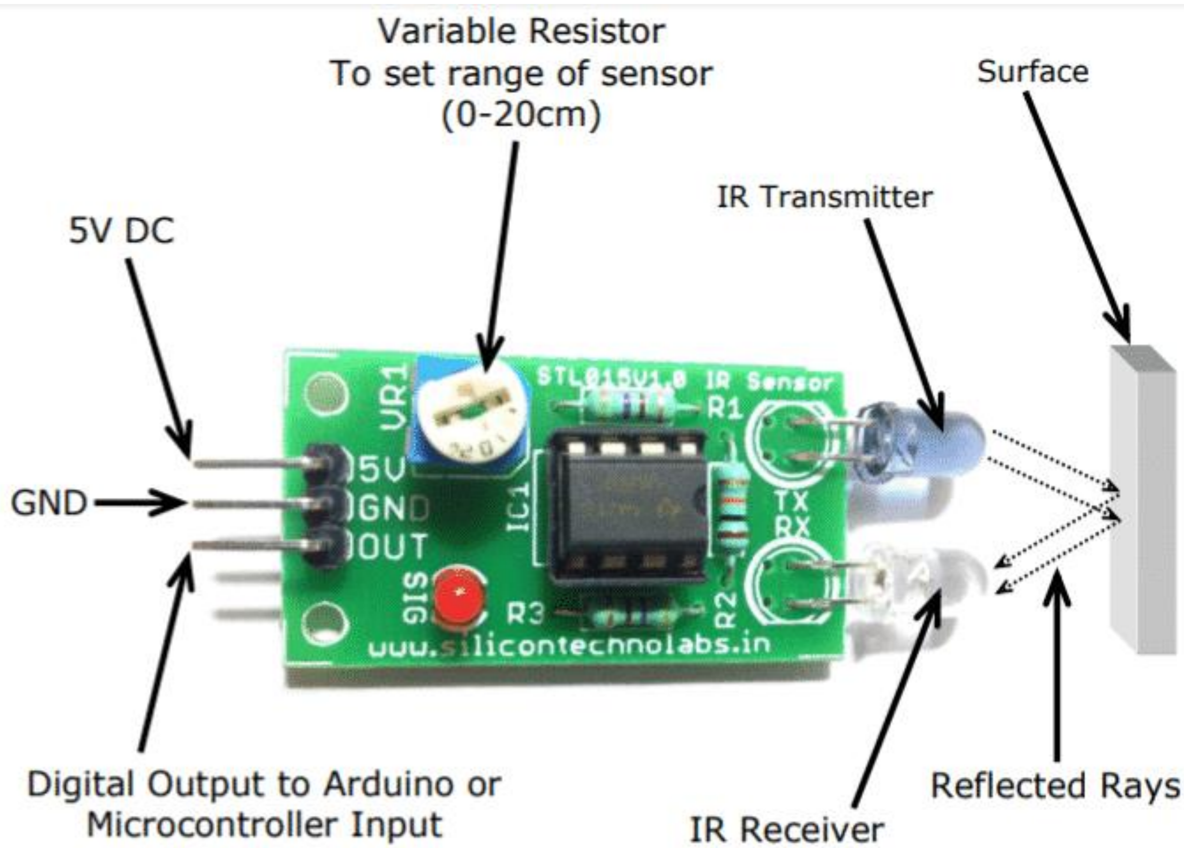
- The PIR sensor generates an output voltage based on the detected infrared radiation. When there is no motion, the output voltage is stable.
- When motion is detected, the PIR sensor's output voltage changes. This change is detected by the operational amplifier or internal circuitry inside the PIR sensor.
- The output signal is then provided at the Signal Output pin. It goes high (logical 1) when motion is detected and low (logical 0) when no motion is present.
- The resistor R1 is used to pull up the Signal Output to Vcc when motion is not detected. This ensures a clear digital signal.
- Depending on the specific PIR sensor model, there may be additional circuitry, such as a comparator or timer, to provide more advanced features like adjustable sensitivity or trigger delay.

Active IR Sensors

1. An IR emitter shoots out a beam of light, facing an in-line receiver.
2. If nothing is in the way, the receiver sees a signal.
3. If the receiver fails to see an IR beam, it detects that an object is between the emitter and the receiver, and therefore present in the monitored area.

One variation of the standard active IR sensor uses an emitter and receiver facing the same direction. The two sit very close to each other so the receiver can detect an object’s reflection when it enters an area. Here’s another twist: a fixed reflector bounces the signal back. This method replicates the setup of separate emitter and receiver units, but without the need to install a remote electrical component. Each method has its advantages and disadvantages based on the material the sensor will be detecting and other specific circumstances.


Trimmer for Calibration
the distance range
IR diode (IR Receiver)
5 Vdc Power Supply
Ground terminal
Digital Output
Photodiode
(IR Receiver)
LM358 Opamp as
Comparator
Obstacle Sensor


Variable Resistor
To set range of sensor
(0-20cm)
Surface
IR Transmitter
5V DC
GND
Digital Output to Arduino or
Microcontroller Input
IR Receiver
Reflected Rays
www.silicontechnolabs.in

Applications of IR sensor

PIR Sensor based Automatic Door Opening System

The main aim of this project is to opening and closing of doors, in places wherein a person's presence is mandatory – for instance, hotels, shopping malls, theaters, etc. this project consists of a PIR sensor that senses the presence of the human body and sends pulses to the 8051 microcontroller. This microcontroller controls the motor driver by sending suitable pulses to its input and enable pins.

Security Alarm System based on PIR sensor

The main intention of this project is to provide security. This project is based on PIR sensor with an integrated circuit which generates a siren. This sensor senses the infrared radiation which is emitted from the humans and then gives a digital output. This digital output is applied to the UM3561 IC. Thus, it generates the sound when any human body is detected. The UM3561 IC is a ROM IC, that generates multi siren tones such as fire engine sirens, ambulance sirens, machine gun sound and police sirens.

Human Detection Robot Using PIR Sensor

The human detection robot using PIR sensor mainly detects human, and it is based on an 8-bit microcontroller. A passive infrared sensors used to detect the human beings and this project is mainly used to rescue people stuck in debris during earthquake. It basically brings humans stuck under debris to the surface, thereby saving them effectively.

PIR Sensor based Stepper Motor Control

The main goal of this project is to control a stepper motor using PIR sensor. This project is mainly based on the robotic technology. This technology is mainly used for advanced applications. In this project, internally PIR sensor is used for excellent performance- IR sensor is used in burglar alarm systems, light switches, visitor present monitoring and robots. In robotics, stepper motors are used widely and they offer continuous rotation as well as amazing precision.

Ultrasonic Sensor

An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves.

An ultrasonic sensor uses a transducer to send and receive ultrasonic pulses that relay back information about an object's proximity.

High-frequency sound waves reflect from boundaries to produce distinct echo patterns.

Ultrasonic sensors work by sending out a sound wave at a frequency above the range of human hearing. The transducer of the sensor acts as a microphone to receive and send the ultrasonic sound. Our ultrasonic sensors, like many others, use a single transducer to send a pulse and to receive the echo. The sensor determines the distance to a target by measuring time lapses between the sending and receiving of the ultrasonic pulse.

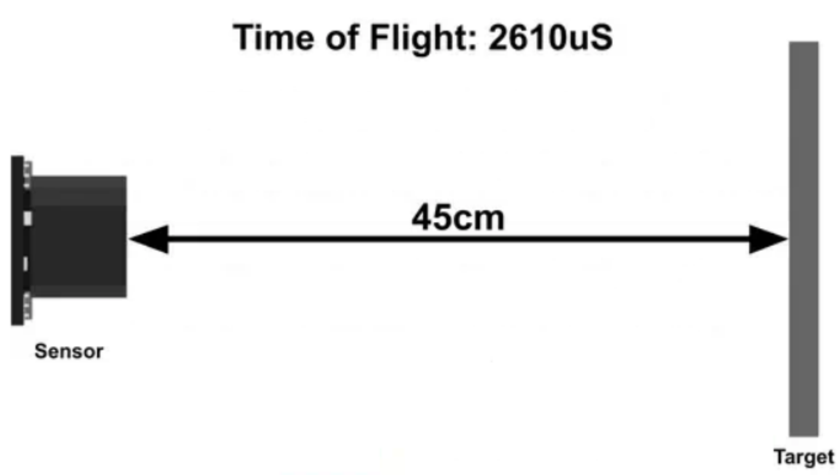
Ultrasonic sensors work based on the principle of sending and receiving sound waves, specifically ultrasonic sound waves, to detect objects and measure distances. Here's how an ultrasonic sensor works:

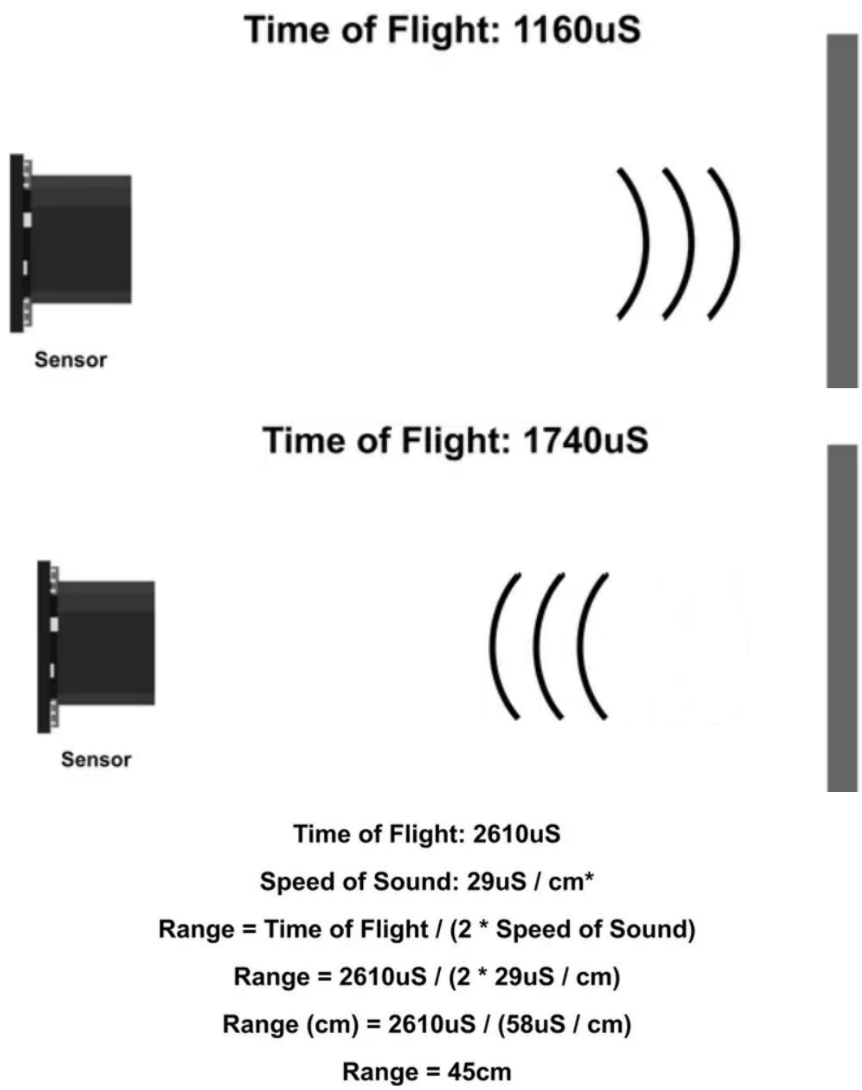
Components:

1. **Transmitter:** The sensor contains a piezoelectric transducer (a type of sensor or speaker) that can emit high-frequency sound waves.
2. **Receiver:** It also has a separate piezoelectric transducer that can detect the sound waves when they bounce back after hitting an object.
3. **Control Circuit:** The sensor includes control circuitry to coordinate the emission and reception of sound waves and measure the time it takes for the sound waves to return.

Working Principle:

1. **Sound Wave Emission:** The ultrasonic sensor's transmitter emits a burst of ultrasonic sound waves, which are inaudible to humans. These sound waves travel through the air at a specific speed, usually at the speed of sound.
2. **Reflection:** When these sound waves encounter an object in their path, some of the waves are reflected back towards the sensor.
3. **Detection:** The reflected sound waves are detected by the sensor's receiver.
4. **Time Measurement:** The control circuit measures the time it takes for the sound waves to travel from the transmitter to the object and back to the receiver. This time is often referred to as the "time of flight."
5. **Distance Calculation:** Using the known speed of sound in the air, the sensor calculates the distance to the object by multiplying the time of flight by the speed of sound and then dividing it by two. This is because the sound waves travel to the object and back.
6. **Output:** The calculated distance is provided as an output from the sensor. Depending on the sensor model, the output can be a digital value (e.g., pulse width modulation or serial data) or an analog value (e.g., voltage level proportional to distance).





To calculate the distance using an ultrasonic sensor, we can use the formula:

$$\text{Distance (in meters)} = (\text{Time of Flight} \times \text{Speed of Sound}) / 2$$

Where:

- Distance is the distance from the sensor to the object in meters.
- Time of Flight is the time taken by the sound wave to travel to the object and back to the sensor in seconds.
- Speed of Sound in air is approximately 343 meters per second at room temperature (20°C or 68°F).

Let's work through an example calculation:

Suppose we have an ultrasonic sensor, and you measure the time it takes for a sound wave to travel to an object and back to the sensor. Let's say the time of flight is 0.01 seconds (10 milliseconds).

$$\text{Distance} = (0.01 \text{ s} \times 343 \text{ m/s}) / 2 \quad \text{Distance} = (3.43 \text{ meters}) / 2 \quad \text{Distance} \approx 1.715 \text{ meters}$$

So, in this example, the distance from the sensor to the object is approximately 1.715 meters.

Applications: Ultrasonic sensors are used in various applications, including:

- **Distance Measurement:** They can measure distances with a high degree of accuracy, making them suitable for applications like object detection, obstacle avoidance, and level measurement.
- **Object Detection:** Ultrasonic sensors can detect the presence or absence of objects, even in the dark, by measuring the distance to the objects.
- **Proximity Sensors:** They are commonly used in robotics, automation, and security systems to determine the proximity of objects or obstacles.
- **Parking Assistance:** Ultrasonic sensors are employed in automotive parking systems to help drivers avoid collisions when parking.
- **Liquid Level Sensing:** In industrial settings, they can measure the level of liquids in tanks and containers.
- **Gesture Control:** Some modern devices use ultrasonic sensors for gesture recognition and touchless control.

Microwave Sensor

Microwave sensors, also known as radar sensors, work on the principle of emitting microwave radio waves and detecting their reflections to detect motion and measure the distance to objects. Here's how a microwave sensor works:

Components:

1. **Transmitter:** The sensor emits continuous microwave radio waves. These waves are typically in the microwave frequency range, such as 2.4 GHz.
2. **Receiver:** The sensor also has a receiver that is sensitive to the reflected microwave signals.
3. **Control Circuit:** The control circuit coordinates the emission of microwave signals and the reception of reflected signals. It analyzes the returned signals to detect motion and determine object distances.

Working Principle:

1. **Microwave Emission:** The microwave sensor continuously emits microwave radio waves into its surroundings. These waves propagate at the speed of light.
2. **Reflection:** When the emitted microwaves encounter an object in their path, some of the waves are reflected off the object.
3. **Detection:** The sensor's receiver detects the reflected microwave signals. The time delay between emission and reception is measured.
4. **Frequency Shift:** If an object is moving, the reflected microwave signals experience a Doppler frequency shift. This shift is due to the motion of the object toward or away from the sensor. The receiver detects this frequency shift.
5. **Analysis:** The control circuit analyzes the time delay and the frequency shift of the reflected microwave signals. The time delay provides information about the distance to the object, and the frequency shift indicates motion.
6. **Distance and Motion Calculation:** The sensor calculates the distance to the object based on the time delay and uses the Doppler frequency shift to detect the direction and speed of the object's motion.
7. **Output:** The sensor provides an output signal indicating the presence of motion and often the distance to the object. The output can be used for various applications, including security, automation, and object detection.

Certainly, let's go through an example of how to calculate the distance to an object using a microwave sensor. To do this, we'll use the speed of light and the time it takes for the microwave signal to travel to the object and back. The formula for calculating distance is:

$$\text{Distance (in meters)} = (\text{Speed of Light} \times \text{Time Delay}) / 2$$

Where:

- Distance is the distance from the sensor to the object in meters.
- Speed of Light in a vacuum is approximately 299,792,458 meters per second.

Let's assume you have a microwave sensor, and it measures a time delay of 5 microseconds (5×10^{-6} seconds) for the microwave signal to travel to the object and back.

Distance = (299,792,458 m/s × 5 × 10^(-6) s) / 2 Distance ≈ 749.48 meters / 2 Distance ≈ 374.74 meters

So, in this example, the distance from the sensor to the object is approximately 374.74 meters.

Applications: Microwave sensors are used in various applications, including:

- **Motion Detection:** They are commonly used in motion-activated lighting and security systems.
- **Automotive Radar:** Microwave radar is used in advanced driver-assistance systems (ADAS) and adaptive cruise control.

- **Industrial Automation:** They are used for object detection and automation in industrial settings.
- **Traffic Radar:** Microwave radar is employed in traffic speed detection by law enforcement and traffic management systems.
- **Robotic Navigation:** Microwave sensors are used in robotics for obstacle detection and navigation.

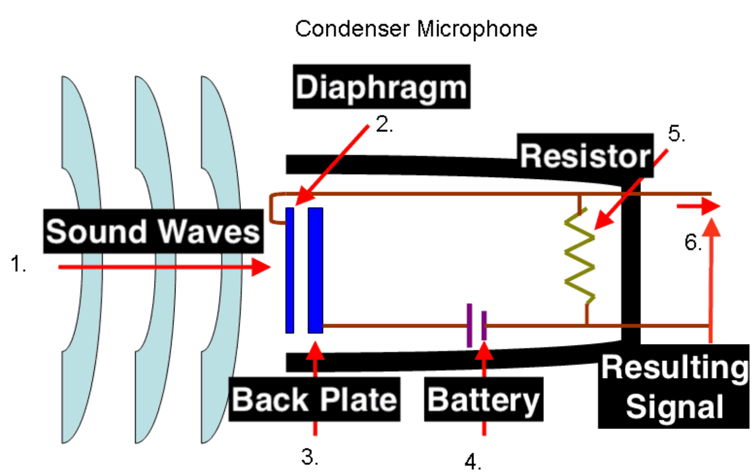
Sound Sensors

Condenser microphones

Condenser microphones, also known as capacitor microphones, operate based on the principle of converting sound waves into electrical signals through changes in capacitance.

Components:

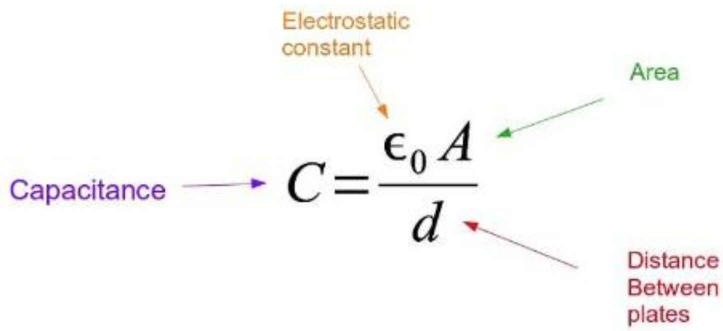
1. **Diaphragm:** The diaphragm is a thin, movable membrane typically made of a lightweight material, such as mylar or gold-sputtered plastic. It acts as one of the capacitor plates.
2. **Backplate:** The backplate is a stationary plate positioned close to the diaphragm. It serves as the other capacitor plate. The gap between the diaphragm and the backplate acts as the dielectric.
3. **Electret:** An electret is a permanent dielectric material with a fixed electrical charge. It is typically applied to the backplate or diaphragm to maintain a constant voltage bias.
4. **External Circuit:** The microphone is connected to an external circuit, which includes a high-impedance preamplifier to amplify the audio signal. This circuit measures changes in capacitance and converts them into voltage variations.



Working Principle:

1. **Sound Wave Detection:** When sound waves enter the microphone, they cause the diaphragm to vibrate in response to changes in air pressure. The diaphragm moves closer to and farther away from the backplate due to these vibrations.

2. **Change in Capacitance:** As the diaphragm moves, the distance between the diaphragm and the backplate changes. This variation in distance results in a change in capacitance in the space between the two plates. Capacitance is a measure of the ability to store an electrical charge.



3. **Capacitance Modulation:** The capacitance changes result in modulation of the electrical charge stored in the capacitor (the diaphragm and backplate with the electret between them). When the diaphragm moves closer to the backplate, the capacitance increases, storing more electrical charge. When the diaphragm moves away, the capacitance decreases, releasing electrical charge.

4. **Voltage Variation:** The external circuit connected to the microphone is sensitive to these changes in capacitance. As capacitance varies, the circuit produces a corresponding voltage change. The output voltage reflects the mimicked audio signal, with the voltage variations proportional to the sound wave vibrations.

$$V_{Battery}=V_{Capacitor}+V_{Resistor}$$

5. **Amplification:** The microphone's output is typically a very low-level signal. To make it usable, it is fed into a high-impedance preamplifier, which boosts the voltage level and prepares it for further signal processing or recording.

Condenser microphones are known for their high sensitivity, wide frequency response, and low self-noise, making them suitable for capturing detailed audio in various applications, such as studio recording, live sound reinforcement, and broadcasting. The electret condenser microphones have a permanently charged dielectric (the electret) and do not require an external power source, while other condenser microphones (non-electret) often require an external phantom power source to maintain the voltage bias across the diaphragm and backplate.

Dynamic Microphone

A dynamic microphone is a type of microphone that operates on the principle of electromagnetic induction to capture audio. It is a durable and versatile microphone commonly used for a wide range of applications, including live sound, broadcasting, recording, and public address systems.

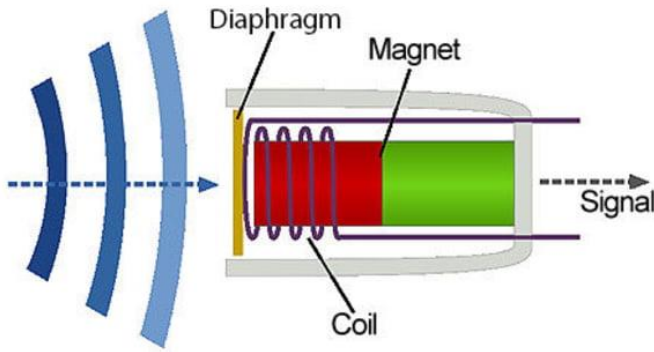
Components:

1. **Diaphragm:** The diaphragm is a thin, movable membrane typically made of lightweight materials, such as mylar or plastic. It is part of the microphone's transducer.

2. **Voice Coil:** Attached to the diaphragm is a voice coil, which is a wire coil that can move within the magnetic field.

3. **Magnet:** A permanent magnet is positioned close to the voice coil. The magnet creates a fixed magnetic field.

4. **Electrical Conductors:** Electrical conductors connect the voice coil to the microphone's output terminals.



Working Principle:

1. **Vibrating Diaphragm:** When sound waves from your voice or an instrument reach the microphone, they cause the diaphragm, which is a thin, flexible membrane, to vibrate. This vibration corresponds to the variations in air pressure created by the sound.

2. **Voice Coil and Magnetic Field:** Inside the microphone, there is a coil of wire called the voice coil, which is attached to the back of the diaphragm. Surrounding the voice coil is a permanent magnet that creates a constant magnetic field.

3. **Electromagnetic Interaction:** As the diaphragm vibrates, it moves the attached voice coil back and forth within the magnetic field. This motion of the voice coil inside the magnetic field results in a change in the magnetic environment experienced by the coil.

4. **Electromagnetic Induction:** According to Faraday's law of electromagnetic induction, when a conductor (in this case, the voice coil) moves within a changing magnetic field, it induces an electrical current in the conductor. In this context, the motion of the voice coil within the magnetic field leads to variations in the magnetic field strength experienced by the coil, resulting in the generation of an electrical current.

5. **Voltage Generation:** The induced electrical current in the wire coil is, essentially, an electrical signal that mimics the vibrations of the diaphragm caused by sound. This induced voltage is directly proportional to the speed and extent of the diaphragm's vibration in response to sound waves.

   Using Faraday's law, the induced voltage ε in the voice coil is directly proportional to the rate of change of magnetic flux through the coil. This can be expressed as:

   $$\varepsilon = -d\Phi/dt$$

   Where:

   ε is the induced voltage (audio signal).

$d\Phi/dt$ represents the rate of change of magnetic flux.

So, as the diaphragm vibrates in response to sound waves, causing the voice coil to move within the magnetic field, the rate of change of magnetic flux through the coil changes. This change induces an electrical voltage (emf) in the coil, which represents the audio signal picked up by the microphone.

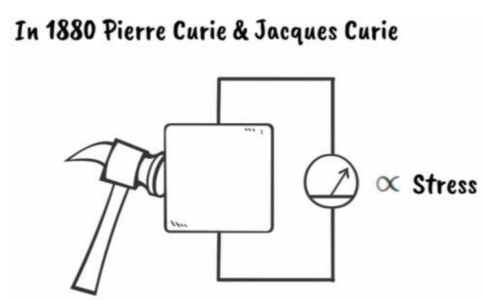
6. **Audio Signal Output:** This induced electrical voltage (audio signal) generated in the voice coil represents the captured sound and is sent to the microphone's output. It can be further processed or amplified to produce the final audio output.

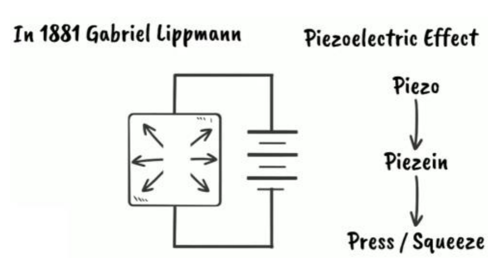
Dynamic microphones are known for their rugged construction, reliability, and ability to handle high sound pressure levels. They are resistant to moisture and temperature variations, making them suitable for stage use and outdoor applications. Dynamic microphones are often used for:

- Live sound reinforcement: They are commonly used for vocals, instruments, and amplifiers in live concerts and performances.
- Studio recording: Dynamic microphones can also be used in studio environments for specific recording applications, such as close-miking musical instruments or for voice-over work.
- Public address systems: They are used in public speaking, conferences, and announcements, where durability and reliability are essential.
- Broadcasting: Dynamic microphones are frequently used in broadcasting studios and news reporting due to their durability and ability to reduce background noise.
- Instrument miking: They are suitable for miking musical instruments like drums, guitar amplifiers, and brass instruments.

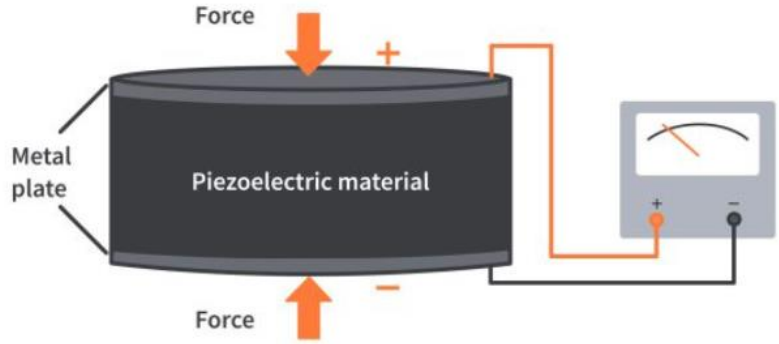
Dynamic microphones are valued for their versatility and robust design, making them a popular choice in a variety of professional audio settings.

Piezoelectric Effect



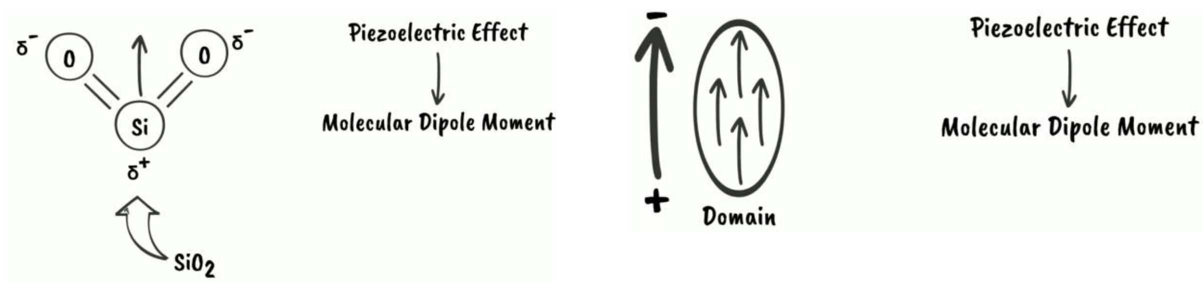


Piezoelectric effect is when compressing a piezoelectric material produces electricity. It occurs when there is a conversion of kinetic or mechanical energy due to crystal deformation, into electrical energy. Piezoelectric materials are materials that can produce electricity due to mechanical stress. When a piezoelectric material is placed under mechanical stress, there is a shift of the positive and negative charge centers in the material, which then results in an external electric field. Going the other direction, with an inverse piezoelectric effect, an external electric field causes a physical deformation in a piezoelectric material.

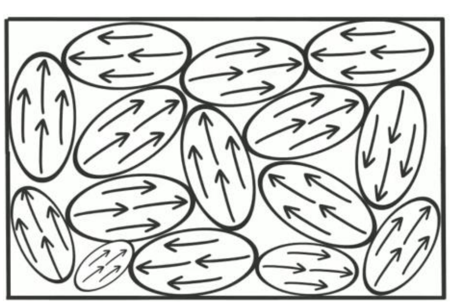


Piezoelectric Materials

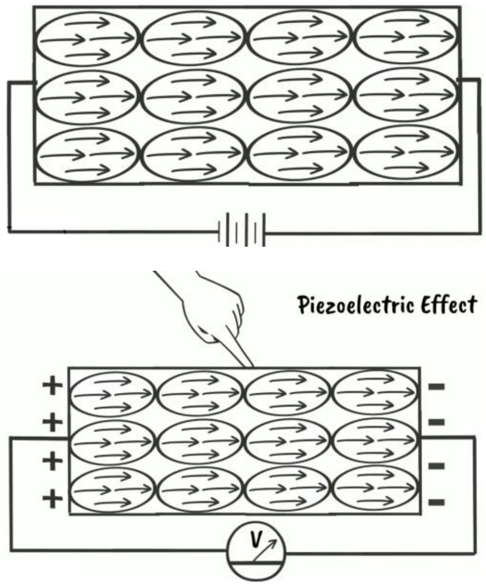
1. **Symmetrical Unit Cell:** In most solid materials, including metals and non-piezoelectric crystals, the unit cell, which is the repeating atomic or molecular arrangement within the material, is symmetrical. This means that the arrangement of atoms is evenly balanced and electrically neutral, with positive and negative charges canceling each other out. There's no net charge on the crystal faces.



2. **Piezoelectric Crystals' Asymmetry:** In contrast, piezoelectric crystals have an asymmetrical unit cell. While the atomic arrangement may not be perfectly symmetrical, the charges are still balanced in their normal state. In other words, any positive charge at one location is canceled out by a nearby negative charge within the crystal.



3. **Deformation and Imbalance:** When a mechanical force is applied to a piezoelectric crystal, such as stretching or compressing it, the crystal's structure is deformed. This deformation pushes some of the atoms closer together or further apart. As a result, the balance of positive and negative charges is disrupted within the crystal.



4. **Net Electrical Charges:** The deformation affects the forces (electric dipole moments) of the charges within the crystal. These dipole moments, which were previously canceling each other out, no longer do so. This imbalance leads to the appearance of net positive and negative charges on opposite faces of the crystal. In other words, the deformation of the crystal creates an electric charge separation within the material.

5. **Voltage Generation:** The effect of the imbalance continues throughout the entire crystal structure, resulting in net positive and negative charges appearing on opposite outer faces of the crystal. As a consequence of this charge separation, a voltage is produced across the crystal's opposite faces.

Piezoelectric Sound Sensor

A piezoelectric sound sensor, commonly referred to as a piezoelectric microphone or piezoelectric transducer, operates based on the piezoelectric effect. This sensor converts sound waves (acoustic pressure variations) into an electrical voltage signal.

Components:

1. **Piezoelectric Crystal:** The core component of the sensor is a piezoelectric crystal, typically made of materials like quartz or lead zirconate titanate (PZT). These materials exhibit the piezoelectric effect, which means they generate an electric charge in response to mechanical stress or pressure.

2. **Electrodes:** The piezoelectric crystal is equipped with electrodes on its surfaces. These electrodes are used to collect the electric charge generated by the crystal.

Working Principle:

1. **Sound Wave Detection:** When sound waves in the form of acoustic pressure waves strike the piezoelectric sensor, they cause the crystal to vibrate. These vibrations are a result of the fluctuations in air pressure corresponding to the sound.

2. **Piezoelectric Effect:** As the crystal vibrates, it experiences mechanical stress due to the pressure variations from the sound waves. This mechanical stress leads to the generation of an electric charge within the crystal. The piezoelectric effect causes the separation of positive and negative charges within the material.

   The piezoelectric effect is described by the equation:

   $$\varepsilon = d \cdot F$$

   Where:

   ε is the electric field or voltage generated (in volts, V).

   d is the piezoelectric coefficient (in volts per newton, V/N). This coefficient is specific to the material used.

   F is the mechanical force or stress applied to the piezoelectric crystal (in newtons, N).

3. **Charge Accumulation:** The positive charges accumulate on one electrode of the piezoelectric crystal, while the negative charges accumulate on the other electrode. This separation of charges results in an electric potential difference (voltage) between the two electrodes.
4. **Voltage Output:** The voltage generated due to the piezoelectric effect is directly proportional to the amplitude of the sound wave. When the sound pressure is high, the generated voltage is also high, and when the sound pressure is low, the voltage is lower.
5. **Signal Measurement:** The voltage output from the piezoelectric sound sensor represents the electrical analog of the sound wave. This voltage signal can be measured and further processed by appropriate electronic circuitry, such as amplifiers or signal conditioning circuits.
6. **Audio Signal Output:** The electrical signal is then used as an audio signal or can be processed, converted into a digital format, and utilized for various applications, including sound recording, acoustic measurements, and other audio-related tasks.

Piezoelectric sound sensors are known for their simplicity, robustness, and ability to capture a wide range of audio frequencies. They are commonly used in applications like contact microphones, sound recording, acoustic instruments (e.g., contact pickups for acoustic guitars), and as vibration sensors for impact detection and security systems. The generated voltage signal accurately represents the sound pressure variations, making piezoelectric sound sensors valuable tools in the field of audio and acoustic engineering.