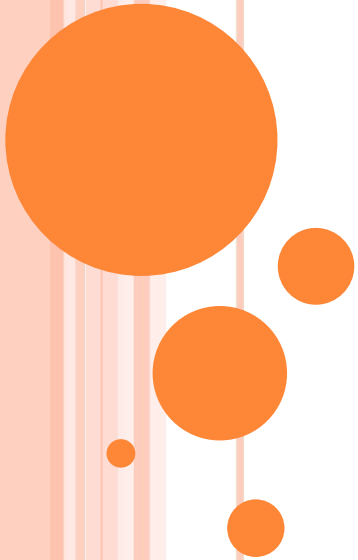
Sensors & Actuators

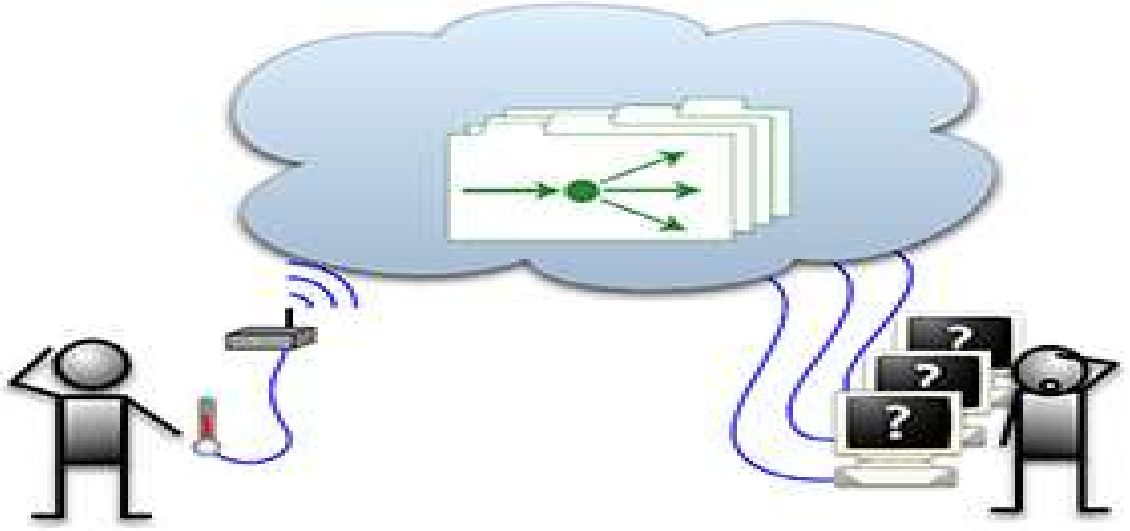


BACKGROUND

- Sensors have been in existence since beginning of civilization in one form or the other
- Sensors became more popular and standardized with the advent of Industrial revolution
- New age sensors have really started doing what sensor should do “Sense” like human sense organs – Multipurpose, sensitive and Reliable.

WHAT IS SENSOR?

- Device that detects and responds to some type of input from the physical environment.
- Output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.



WHAT IS AN ACTUATOR?

- Type of motor that is responsible for moving or controlling a mechanism or system.
- Mechanism by which a control system acts upon an environment.

Types of Actuators

- **Hydraulic**
- **Pneumatic**
- **Electric**
- **Mechanical**

WHAT IS GOOD SENSOR?

- Is sensitive to the measured property only
- Is insensitive to any other property likely to be encountered in its application
- Does not influence the measured property
- Is sturdy and compact

Sensor Properties

- Sensor Range: range of the output signal of a sensor is generally limited, The full scale range defines the maximum and minimum values of the measured property.
- Bias: If the output signal is not zero when the measured property is zero, the sensor has an offset This is defined as the output of the sensor at zero input.
- Non linearity: Usually this is defined by the amount the output differs from ideal behavior over the full range of the sensor, often noted as a percentage of the full range.
- Dynamic error: Deviation in reading caused by a rapid change of the measured property over time.

Sensor Properties:

- Drift: If the output signal slowly changes independent of the measured property. Seen in most sensors.
  - Long term drift: indicates a slow degradation of sensor properties over a long period of time.
- Noise: is a random deviation of the signal that varies in time
- Digitization error: If the sensor has a digital output, the output is essentially an approximation of the measured property

Types of Sensor

- Acoustic, Sound, Vibration
- Automotive, Transportation
- Chemical
- Environment, weather, moisture, humidity
- Flow, fluid velocity
- Navigation instruments
- Optical, light, imaging, photo.
- Proximity, presence
- Electric current, electric potential, magnetic, radio

Passive vs. Active

- Passive detectors *react* to signals, such as sound waves or heat spikes.
- Active detectors *emit* signals that are reflected back to the sensor.

Passive Infrared (PIR)

- Passive Infrared Detectors use a sensor that detects infrared radiation.
- The PIR considers a temperature range as "normal" and anything else as reason to raise the alarm.
- This range is usually between 59-68°F.
- Sudden changes in temperature trip the detector.

Ultrasonic Detectors

- These are active sensors that emit ultrasonic waves that reflect off objects.
- An object in motion will reflect faster because the distance between the detector and the object is shorter.

Dual-Technology

- More effective than a single-type motion sensor
- False alarms are less likely to happen
- Usually a combination of PIR and Microwave
- Both must be activated to trip the alarm.

Mems sensor

What is MEMS?

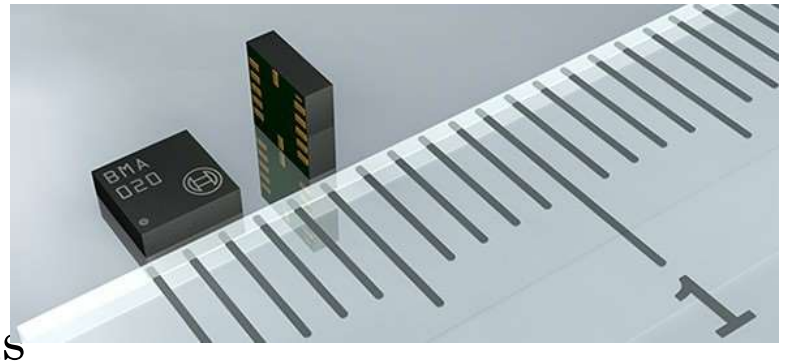
- MEMS or Micro-Electro Mechanical System is a technique of combining Electrical and Mechanical components together on a chip, to produce a system of miniature dimensions.

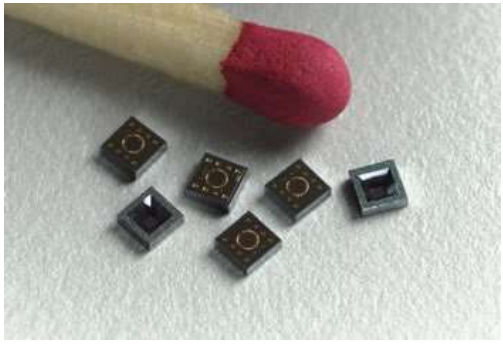
- MEMS is the integration of a number of micro-components on a single chip which allows the micro system to both sense and control the environment.

- The components are integrated on a single chip using micro fabrication technologies.

But why MEMS for sensors?

- Smaller in size
  - Typically .1-100um feature size
- Have lower power consumption
- More sensitive to input variations
- Cheaper due to mass production
- Less invasive than larger devices



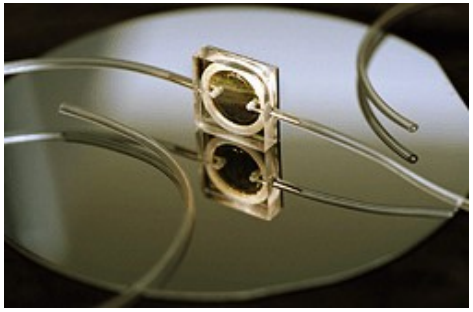


Who Developed It

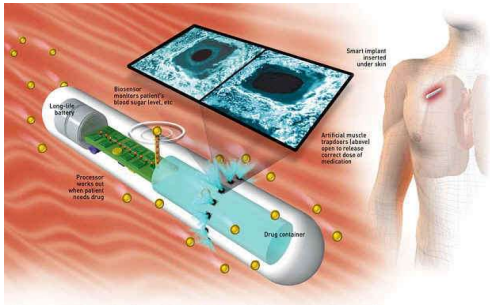
- Two groups
  - Delco Electronics Group(General Motors)
    - Used piezoresistive sensing.
  - Ford
    - Used capacitive sensing.

APPLICATIONS

- **Biocavity Laser :** This device distinguishes cancerous from non cancerous cells thus aiding the surgeons in operations.



- **Smart Pill** :
  - Implanted in the body
  - Automatic drug delivery (on demand)



- **Sight for the blind** : MEMS based array that may be inserted in the retina of a blind person to provide partial sight

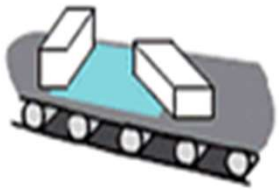
Applications

daily life monitor
for safty

industrial robot
(perfect gripping)

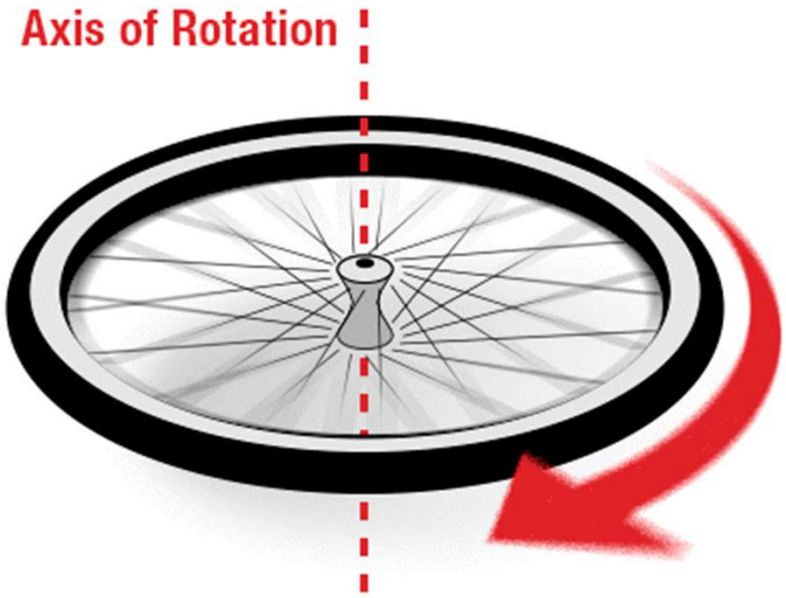
New UI

tire sensor



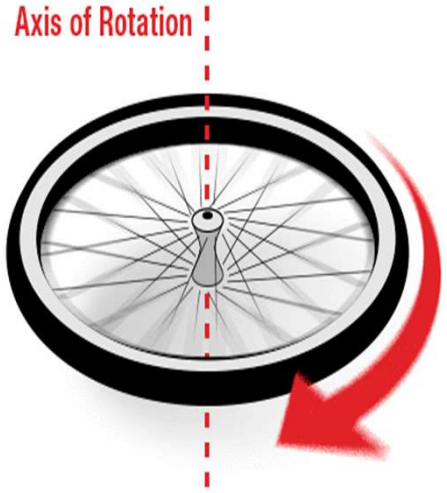
smart belt conveyer

Gyroscope Sensor



What is a Gyroscope

- Sensor that measures the angle or maintain the rate of rotation.
- MEMS gyros are small, inexpensive sensors that measure angular velocity.
- The units of angular velocity are measured in degrees per second (°/s) or revolutions per second (RPS).
- Angular velocity is simply a measurement of speed of rotation.



How to connect to Gyro

- The primary hardware connections to use a gyro are power and a communication interface.

Communication Interface

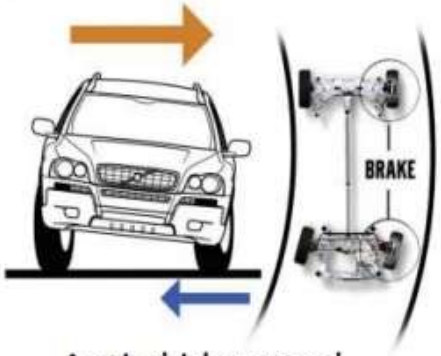
Gyros can have either a digital or analog communication interface.

- Gyros with a *digital* interface usually use either the SPI or I2C communication protocols.

- Gyros with an *analog* interface represent rotational velocity by a varying voltage, usually between ground and the supply voltage.

Applications of MEMS Gyroscopes

Automotive: Reliability



Anti-skid control

Industrial: Robustness

Antenna stabilization

Precision machinery

Consumer: Size & Cost

Gaming

Health and fitness

Optical Image Stabilization

Pedestrian Navigation

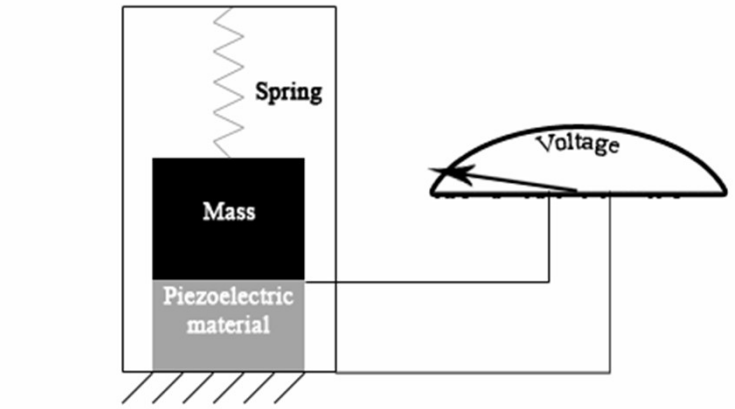
ACCELEROMETER

What is an Accelerometer?

- Accelerometers are devices that measure acceleration, which is the rate of change of the velocity of an object.
- They measure in meters per second squared (m/s^2) or in G-forces (g).
- Accelerometers are useful for sensing vibrations in systems or for orientation applications.

How an Accelerometer Works ?

- Accelerometers are electromechanical devices that sense either static or dynamic forces of acceleration.
- Static forces include gravity, while dynamic forces can include vibrations and movement.



How to Connect to an Accelerometer

For most accelerometers, the basic connections required for operation are power and the communication lines. As always, read the datasheet to ensure proper connections are made.

Communication Interface

- Accelerometers will communicate over an analog, digital, or pulse-width modulated connection interface.
- Accelerometers with an analog interface show accelerations through varying voltage levels. These values generally fluctuate between ground and the supply voltage level.

- These are generally less expensive than digital accelerometers.
- Accelerometers with a digital interface can either communicate over SPI or I2C communication protocols. These tend to have more functionality and be less susceptible to noise than analog accelerometers.

Applications of MEMS Accelerometers

Industrial
- Platform stabilization
- Oil drilling orientation
- Robotic telepresence

Automotive
- Airbag deployment
- Rollover, anti-skid control

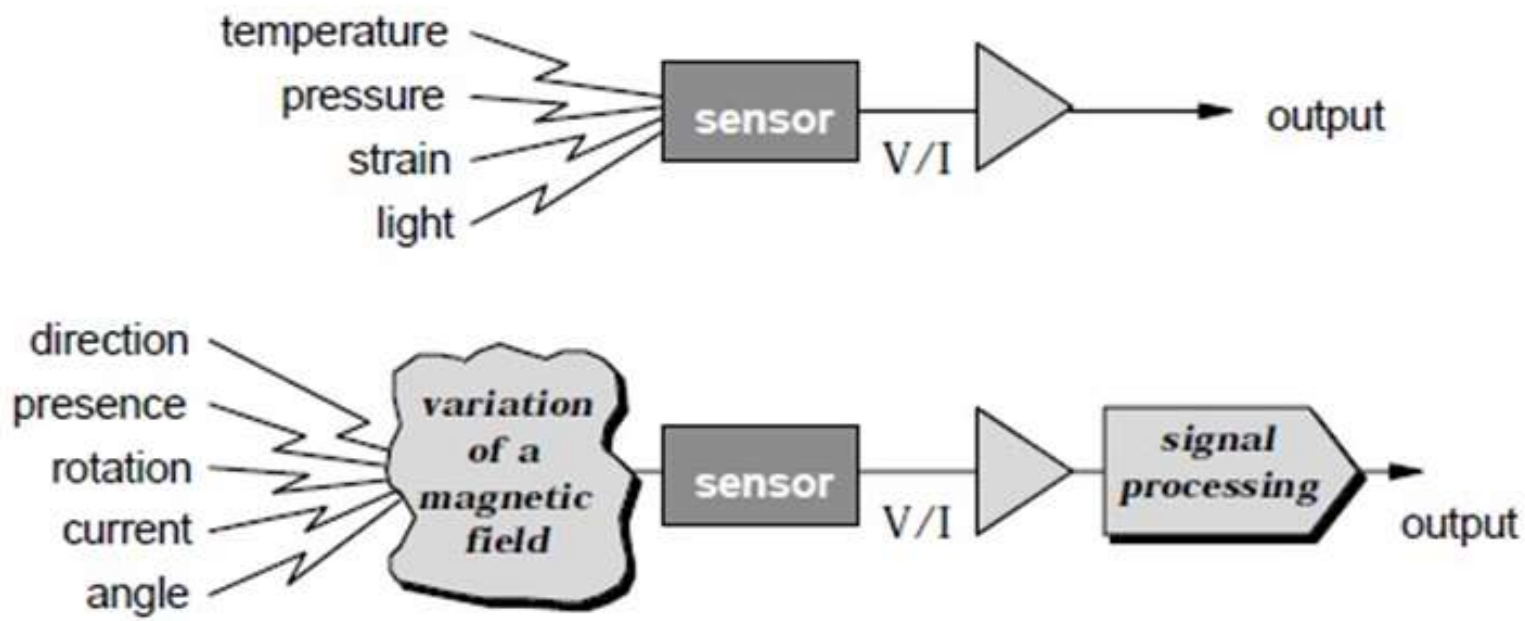
Consumer
- Interactive gaming
- Free-fall detection
- Camera stabilization
- Indoor navigation

Military
- Aircraft flight control
- Dead-reckoning

Magnetic Sensor

- The Sensors, transducers which uses the changes in magnetic field for their operations.
- Used to measure the currents, speed, position and Displacement.
- As the conventional sensors, Magnetic sensor does not give output parameters directly.
- Signal processing is required for desired output.

Difference between Conventional and Magnetic Sensors:



Conventional vs. Magnetic Sensing

Radio Frequency Sensor

- Operate upto 1 GHz
- Operate from -170° to >1,000°C
- Have low power consumption making them ideal for wireless applications

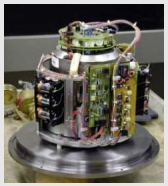
RF technology works with

- Ferrous metals
- Non ferrous metals
- Composites
- Glasses
- Plastics
- Liquids

Applications:

- Sensors to measure rotational speed and position at high temperature for automotive and aerospace applications.
- Remote Sensors to measure temperatures to >1,000°C
- Sensors to detect lateral drift of rubber conveyor belts
- Sensors to discriminate opaque plastics for recycling, including ABS with and without FR
- Sensors to detect water in oil down to 1 ppm
- Sensors to detect particulates in fluids
- Sensors to detect chemical change in fluids

ACOUSTIC,SOUND,VIBRATION SENSOR

Sensor Name	Description	Application
Hydrophone 	• For recording or listening to underwater sound	Under water Exploration, Deep Ocean Operation
Seismometer 	• Measure motions of the ground, including those of seismic waves generated by earthquakes, volcanic eruptions.	EarthQuake Detection, Detection earth quakes in oceans, volcanic Eruptions
Microphone 	• Acoustic-to-electric transducer or sens or that converts sound in air into an electrical signal	Telephones, Tape Recorders, Hearing aids, motion picture production

Automotive, Transportation Sensor

Sensor Name	Description	Application
A blind spot monitor 	• Sensor that detects other vehicles located to the driver's side and rear	In large vehicles like Trucks, cars, air crafts, motor boats
Curb feeler 	• Used to warn driver of curbs	They are fixed on the lower side of a vehicle body, close to the wheels.
Defect detector 	• Used on railroads to detect axle and signal problems in passing trains	Railway tracks
Engine coolant temperature sensor, or ECT sensor 	• Used to measure the engine temperature	Sensor that is screwed into the engine's block or cylinder head
Hall effect sensor 	• Used for proximity switching, positioning, speed detection, and current sensing applications.	automotive Fuel Level Indicators, brushless DC motor, aviation aerospace

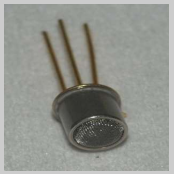
AUTOMOTIVE, TRANSPORTATION SENSOR

Sensor Name	Description	Application
Parking sensors 	• used to alert the driver of unseen obstacles during parking maneuvers	Automobiles like car, trucks, bus, aircrafts
water-in-fuel sensor 	• Used to indicate the presence of water in fuel	Common Rail engines
Wheel speed sensor 	• Used for reading the speed of a vehicle's wheel rotation	Anti lock breaking systems, motor vehicles
Speed sensor 	• Used to detect the speed of an object	Automotive, aviation aero space, rail road, power generation
Oxygen sensor 	• Used to monitor the amount of oxygen in the exhaust	Soil respiration, Medical, Food packaging industry, waste management.

Chemical Sensors

Sensor Name	Description	Application
Breathalyzer 	• Estimating blood alcohol content (BAC) from a breath sample.	Medical, pubs, bars, Restaurant, Highways, criminal prosecution
Carbon dioxide sensor 	• Measurement of carbon dioxide gas	Indoor air quality , Industrial processes
Chemical field-effect transistor 	• To detect atoms, molecules, and ions in liquids and gases	Aqueous environments, sea water
Electronic nose 	• Is a device intended to detect odors or flavors.	R & D Laboratories. Quality control Laboratories, process & Production Departments, health & Security, Environmental monitoring
Holographic sensor 	• That comprises a hologram embedded in a smart material that detects certain molecules or metabolites	Clinical trials, medical diagnostic applications.

Chemical Sensors

Sensor Name	Description	Application
Hydrogen sensor 	• detects the presence of hydrogen. They contain micro-fabricated point-contact hydrogen sensors and are used to locate leaks	Diesel engines, monitoring hydrogen windage in power plants, fossil fuel oil refining, UPS power systems,
Infrared sensor 	• a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light	Industrial, scientific, medical, night vision devices, tracking, smart phones
Smoke detector 	• also called a smoke alarm is a device that detects smoke, typically as an indicator of fire	Commercial, industrial, and mass residential devices

Environment, Weather, Moisture, Humidity Sensor

Sensor Name	Description	Application
Ceilometers 	• device that uses a laser or other light source to determine the height of a cloud base	Weather stations, monitoring of dust and volcanic ash clouds, estimation of particulate matter concentration.
Dew warning 	• is an error indication on VCRs and camcorders if the VCR/camcorder develops dew inside the unit from being exposed to extreme temperature and/or humidity changes	VCRs, Cam recorder
Fish counter 	• for measuring the number of fish passing along a particular river in a particular period of time	Counting of fish in river, sea and oceans

ENVIRONMENT, WEATHER, MOISTURE, HUMIDITY SENSOR

Sensor Name	Description	Application
Frequency domain sensor 	• Sensor is an instrument developed for measuring soil moisture content	Agriculture, Coastal areas
Gas detector 	• Is a device which detects the presence of various gases within an area, usually as part of a safety system and also detect leaks.	Industries, Home, chemical, pharmaceutical, Food and Beverage Industries.
Hygrometer 	• Is an instrument used for measuring the moisture content in the atmosphere	Weather stations, Green houses, Industrial spaces, Incubators, Wooden musical instruments like guitars and violins.
Leaf sensor 	• Is a phytometric device that measures water loss or the water deficit stress (WDS) in plants	Agri house, aerophonic growing

Environment, weather, moisture, humidity Sensor

Sensor Name	Description	Application
Pyrgeometer 	• that measures the atmospheric infra-red radiation spectrum	Meteorology, Climatology
Rain gauge 	• instrument used to gather and measure the amount of liquid precipitation over a set period of time	Meteorology, Hydrology and in weather forecast
Rain sensor 	• a switching device activated by rainfall	Irrigation, Automobiles
Tide gauge 	• for measuring the change in sea level relative to a datum. Sensors continuously record the height of the water level .	satellite radar altimeters Improvement of the tide models, usually in complex coastal zones Evaluation of the spatial altimetry results Validation of the climate models

FLOW, FLUID VELOCITY SENSOR

Sensor Name	Description	Application
Air flow meter 	• Measures air flow, i.e. how much air is flowing through a tube	Industries, automobiles
Anemometer 	• Measuring wind speed	Weather station, Marines, Aviation, Power & Energy, Cranes, Disaster control
Flow sensor 	• Sensing rate of fluid flow through a given area • Acceleration, frequency, pressure and volume	flow meter, or flow logger in industries.
Mass flow sensor 	• Is used to find out the mass flow rate of air entering a fuel injected internal combustion engine.	Automobiles, Industries, aircrafts

Navigation Instruments

Sensor

Sensor Name	Description	Application
MHD sensor 	• used for precision measurements of angular velocities in inertia navigation systems .	surviving in harsh environments, Aerospace, Ship engines
Yaw rate sensor 	• measures a vehicle's angular velocity around its vertical axis	Automotive applications

OPTICAL, LIGHT, IMAGING, PHOTO SENSOR

Sensor Name	Description	Application
Flame detector 	• that uses optical sensors to detect flames	Gas fuelled cookers, Industrial heating and drying systems, Domestic heating systems, Industrial gas turbines
Optical position sensor 	• measure a position of a light spot in one or two-dimensions on a sensor surface	Cameras, Fly by wire Air craft systems, Bullet trains taking curve, Injection molding machines, Packaging machines, Medical Equipments
Photoelectric sensor 	• device used to detect the distance, absence, or presence of an object by using a light transmitter, often infrared, and a photoelectric receiver	industrial manufacturing, Through-beam sensors , Retro-reflective sensors , Diffuse reflection sensors

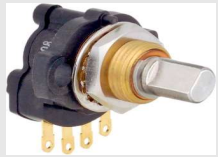
PROXIMITY, PRESENCE SENSOR

Sensor Name	Description	Application
Alarm sensor 	• That can sense an abnormal condition within the system and provide a signal indicating the presence or nature of the abnormality to either a local or remote alarm indicator	Telecommunication, Physical Security, Electronic Security
Motion detector 	• Detects moving objects, particularly people	Home, Security.
Occupancy sensor 	• Is a lighting control device that detects occupancy of a space by people and turns the lights on or off automatically	Home, Industries, Restrooms, Conference Training Rooms

PROXIMITY, PRESENCE SENSOR

Sensor Name	Description	Application
Proximity sensor 	• is a sensor able to detect the presence of nearby objects without any physical contact	Smart phones, Parking Sensors, Ground proximity warning system, Sheet breaking sensing
Triangulation sensor 	• Are commonly used to provide door mounted safety detection on swinging automatic doors.	Micro wave , Cameras, Automatic swinging doors,
Touch switch 	• A type of switch that only has to be touched by an object to operate	Lamps Wall Switches

Electric current, electric potential, magnetic, radio Sensor

Sensor Name	Description	Application
Current sensor 	• detects electrical current (AC or DC) in a wire, and generates a signal proportional to it.	Industries, Solar, Motor Monitoring, Heaters.
Hall effect sensor 	• is a transducer that varies its output voltage in response to a magnetic field	Industries, Solar, Motor Monitoring, Heaters.
Metal detector 	• detects the presence of metal nearby	Air port Security, Building security, Event security, Item Recovery, Archeological, Geological Research
Radio direction finder 	• for finding the direction to a radio source	Sea navigation, Aircraft Navigation.

Top Sensor Manufacturers

Company	Manufacture	Country / URL
STMicro Electronics 	• Accelerometers • Automotive Sensors • Gyroscopes, Humidity Sensors, MEMS Microphones • Pressure Sensors • Proximity Sensors • Smart Sensors and Sensor Hubs, Temperature Sensors	Almost all over the World / http://www.st.com/ **India** : Pune, Bangalore, Mumbai,Noida
	• Acceleration Sensor • Gyroscope Sensor • Geomagnetic Sensor • eCompass • Absolute orientation Sensor. • Environmental Sensor	Almost all over the World / http://www.bosch-sensortec.com/en/
	• Temperature • Current • Hall Effect • Pressure	Texas, USA / http://www.ti.com/

Company	Manufacture	Country / URL
	• Gyroscopes, Humidity Sensors, MEMS Microphones • Proximity Sensors • Smart Sensors and Sensor Hubs, Temperature Sensors	www.hp.com
Panasonic	• Light Sensor • Motion Sensor • Pressure Sensor • Acceleration Sensor	Almost all over the World / www.panasonic.com
	• Accelerometer • Ultrasonic Sensor	Santa Clara, CA/ http://www.knowles.com /

Company	Manufacture	Country / URL
	• Rain Sensor	Italy / http://www.deltaohm.com /
	• Force, torque , • pressure sensors, • signal conditioners, • digital displays, custom-tailored transducers	Irvine, CA / http://www.futek.com/
	• Pressure Sensors, • pressure transducers	Morgan Hill, CA / http://www.allsensors.com /
	• High-Resolution Digital Proximity Sensor	Singapore, Europe, Austria, Japan Korea, Spain and more.. / http://www.omron-ap.com/

Company	Manufacture	Country / URL
	• Machine vision sensors, • proximity sensors, • fiber optic sensors, • photoelectric sensors, • pressure sensors & shock resistant sensors.	Stone Mountain, GA / http://4tsi.com/
	• Fast Laser Diode Oxygen • AnalyzersOxygen Sensors	Mountain View, CA / http://www.oxigraf.com/
	• A wide range of smart sensors, weather stations, water quality sensors from Monitor Sensors	Australia / http://www.esis.com.au/
	• specializing in the design & development of standard flow switches & level switches, gauges, floats & water & liquid level or flow controls.	Southington, CT, US / http://www.thomasprod.com/

Company	Manufacture	Country / URL
	• Gas & flow sensors. • Types include gas steam & liquid Vortex flow meters & fluid & gas sensors.	Omaha, NE / http://www.centralstatesgroup.com/
	• Bi-directional meters for wind, • solar, and other alternative energy applications.	Santa Ynez / http://www.ezmeter.com/
	• Ultrasonic Sensor	Hinesburg, VT / http://www.senix.com/
	• switch proximity, • motor protector, • photoelectric & proximity, • Humidity	Melville, NY / http://www.mscdirect.com/

Company	Manufacture	Country / URL
MFML	• Ultrasonic flow sensor, • Water flow sensor, • Gear flow sensor,G • Gas flow sensor	Pune , India/ http://www.flowtechin.com/
Environmend LETS DO OUR PART	• Aviation lights, • street lights, cables, • Smoke detectors, road lights, marine lights, • Fuel *sensors*, studio lighting	Vadodara, Gujarath, India / http://www.environmend.in/
Arc Ventures	• Energy saving devices, • passive infrared **sensor**, • Twilight switch, • Infrared**sensor**, occupancy **sensor**, photo **sensor**, pir switch	Pune, India / http://www.arcventures.co.in/
Tej Security SYSTEMS	• Electric **sensor**s, • Beam **sensor**, • Shutter **sensor** • smoke **sensor**, wired door **sensor**, wired window **sensor**	Gurgaon, India / http://www.tejsecuritysystems.co.in/

Company	Manufacture	Country / URL
	• water tank level **sensor**s, • Sump tank **sensor**, • Over head tank **sensor**, • Automatic water level controller	Goa, India / http://www.kayleecontrols.com /
	• Pir motion **sensor**s, • ipad control light, • Energy saving **sensor**s, • Occupancy **sensor**, • Human body **sensor**, • Presence **sensor**	New Delhi, India / http://www.kambojenterprises.net/
	• Automatic weather station, • open pan evaporimeter, • sunshine recorder, • Digital solar radiation recorder, • Digital rainfall recorder, • Ordinary rain gauge, • Automatic wind monitor, • Anemometer, • Snow gauge, • Thermo hygrograph, • Digital psychrometer	New Delhi, India / http://www.meteorologicalinstruments.co.in/

Company	Manufacture	Country / URL
ASIATECH ELECTRONICS	• Electric fence digital voltmeter, • Electric fence energizer, • Electric fence lightning diverter, • Electric fence sensor	Kerala, India / http://www.asiatechsolar.com/
minilec®	• Voltage scanners, • voltage controllers, • Motor protection relays, • Current **sensors**, • Winding protection relays	Pune , India / http://www.minilecgroup.com/
NILA TECH PRIVATE LIMITED	• Temperature **sensors**, • Temperature compensator, • Surge current protection • Thermistors, **sensors**	Kerala, India / http://www.nilatech.co.in/
HILTON Trading Co.	• **sensors**, • Photoelectric **sensors**, • proximity **sensors**, • Rotary encoders, • Sequence controller, • Temperature controllers,	New Delhi, India / http://www.hiltontrading.in/

Technical Data Sheet

National Semiconductor

December 1994

LM35/LM35A/LM35C/LM35CA/LM35D Precision Centigrade Temperature Sensors

General Description

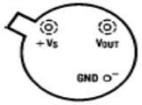
The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-202 package.

Features

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±¼°C typical
- Low impedance output, 0.1 Ω for 1 mA load

Connection Diagrams

TO-46
Metal Can Package*



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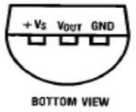
*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

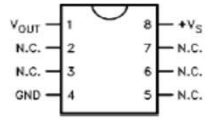
TO-92
Plastic Package



TL/H/5516–2

Order Number LM35CZ, LM35CAZ or LM35DZ
See NS Package Number Z03A

SO-8
Small Outline Molded Package



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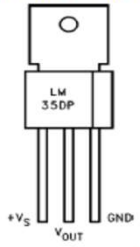
Top View
N.C. = No Connection

Order Number LM35DM
See NS Package Number M08A

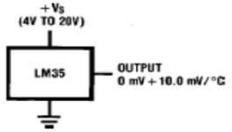
TO-202
Plastic Package



TL/H/5516–24

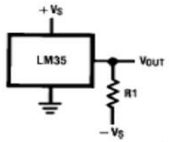
Order Number LM35DP
See NS Package Number P03A

Typical Applications



TL/H/5516–3

FIGURE 1. Basic Centigrade Temperature Sensor (+2°C to +150°C)



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Choose $R_1 = -V_S/50\ \mu A$

$V_{OUT} = +1{,}500$ mV at +150°C
$= +250$ mV at +25°C
$= -550$ mV at −55°C

FIGURE 2. Full-Range Centigrade Temperature Sensor

TRI-STATE® is a registered trademark of National Semiconductor Corporation.

LM35/LM35A/LM35C/LM35CA/LM35D Precision Centigrade Temperature Sensors

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp., TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C
SO-8 Package,	−65°C to +150°C
TO-202 Package,	−65°C to +150°C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300°C
TO-92 Package, (Soldering, 10 seconds)	260°C
TO-202 Package, (Soldering, 10 seconds)	+230°C
SO Package (Note 12):	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	−55°C to +150°C
LM35C, LM35CA	−40°C to +110°C
LM35D	0°C to +100°C

Electrical Characteristics (Note 1) **(Note 6)**

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	$T_A = +25°C$	±0.2	±0.5		±0.2	±0.5		°C
	$T_A = -10°C$	±0.3			±0.3		±1.0	°C
	$T_A = T_{MAX}$	±0.4	±1.0		±0.4	±1.0		°C
	$T_A = T_{MIN}$	±0.4	±1.0		±0.4		±1.5	°C
Nonlinearity (Note 8)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	°C
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/°C
Load Regulation (Note 3) $0 \le I_L \le 1$ mA	$T_A = +25°C$	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	$T_A = +25°C$	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V \le V_S \le 30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	$V_S = +5V, +25°C$	56	67		56	67		µA
	$V_S = +5V$	**105**		**131**	**91**		**114**	µA
	$V_S = +30V, +25°C$	56.2	68		56.2	68		µA
	$V_S = +30V$	**105.5**		**133**	**91.5**		**116**	µA
Change of Quiescent Current (Note 3)	$4V \le V_S \le 30V, +25°C$	0.2	1.0		0.2	1.0		µA
	$4V \le V_S \le 30V$	**0.5**		**2.0**	**0.5**		**2.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, $I_L = 0$	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J = T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Note 1: Unless otherwise noted, these specifications apply: $-55°C \le T_J \le +150°C$ for the LM35 and LM35A; $-40° \le T_J \le +110°C$ for the LM35C and LM35CA; and $0° \le T_J \le +100°C$ for the LM35D. $V_S = +5Vdc$ and $I_{LOAD} = 50$ µA, in the circuit of *Figure 2*. These specifications also apply from +2°C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400°C/W, junction to ambient, and 24°C/W junction to case. Thermal resistance of the TO-92 package is 180°C/W junction to ambient. Thermal resistance of the small outline molded package is 220°C/W junction to ambient. Thermal resistance of the TO-202 package is 85°C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Electrical Characteristics (Note 1) **(Note 6)** (Continued)

Parameter	Conditions	LM35			LM35C, LM35D			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy, LM35, LM35C (Note 7)	$T_A = +25°C$ $T_A = -10°C$ $T_A = T_{MAX}$ $T_A = T_{MIN}$	±0.4 ±0.5 ±0.8 ±0.8	±1.0 ±1.5 	 ±1.5	±0.4 ±0.5 ±0.8 ±0.8	±1.0 	 ±1.5 ±1.5 ±2.0	°C °C °C °C
Accuracy, LM35D (Note 7)	$T_A = +25°C$ $T_A = T_{MAX}$ $T_A = T_{MIN}$				±0.6 ±0.9 ±0.9	±1.5 	 ±2.0 ±2.0	°C °C °C
Nonlinearity (Note 8)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	°C
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/°C
Load Regulation (Note 3) $0 \le I_L \le 1$ mA	$T_A = +25°C$ $T_{MIN} \le T_A \le T_{MAX}$	±0.4 **±0.5**	±2.0 	 **±5.0**	±0.4 **±0.5**	±2.0 	 **±5.0**	mV/mA mV/mA
Line Regulation (Note 3)	$T_A = +25°C$ $4V \le V_S \le 30V$	±0.01 **±0.02**	±0.1 	 **±0.2**	±0.01 **±0.02**	±0.1 	 **±0.2**	mV/V mV/V
Quiescent Current (Note 9)	$V_S = +5V, +25°C$ $V_S = +5V$ $V_S = +30V, +25°C$ $V_S = +30V$	56 **105** 56.2 **105.5**	80 82 	 **158** **161**	56 **91** 56.2 **91.5**	80 82 	 **138** **141**	µA µA µA µA
Change of Quiescent Current (Note 3)	$4V \le V_S \le 30V, +25°C$ $4V \le V_S \le 30V$	0.2 **0.5**	2.0 	 **3.0**	0.2 **0.5**	2.0 	 **3.0**	µA µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.7**	**+0.39**		**+0.7**	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, $I_L = 0$	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J = T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/°C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in °C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of *Figure 1*.

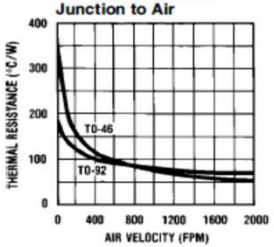
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

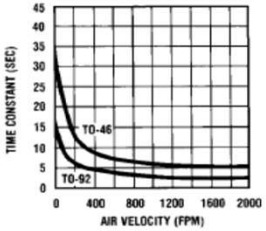
Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

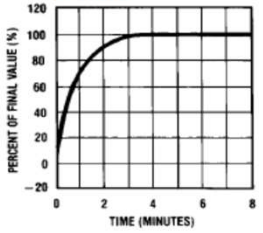
Thermal Resistance Junction to Air



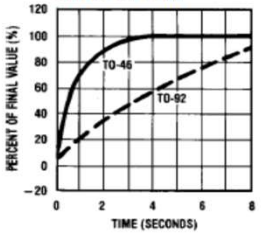
Thermal Time Constant



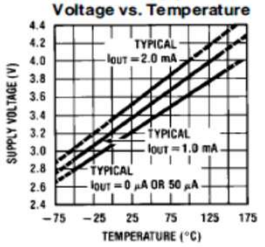
Thermal Response in Still Air



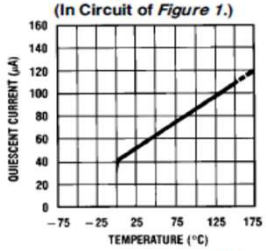
Thermal Response in Stirred Oil Bath



Minimum Supply Voltage vs. Temperature



Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)



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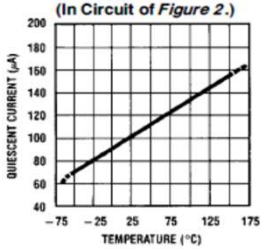
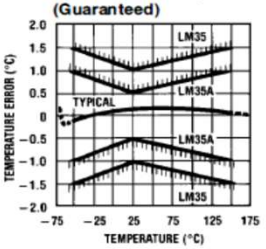
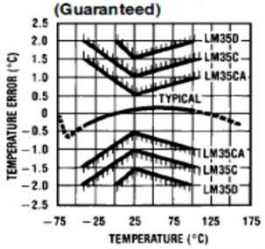
Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



Accuracy vs. Temperature (Guaranteed)



Accuracy vs. Temperature (Guaranteed)



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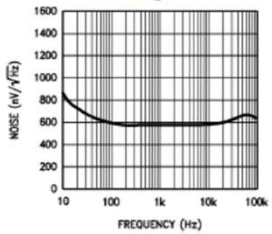
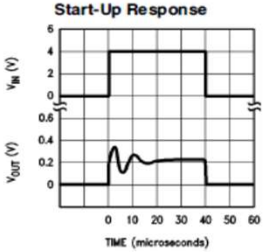
Noise Voltage



Start-Up Response



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