CE 432 Robotics II

Sensors/Transducers and Actuators

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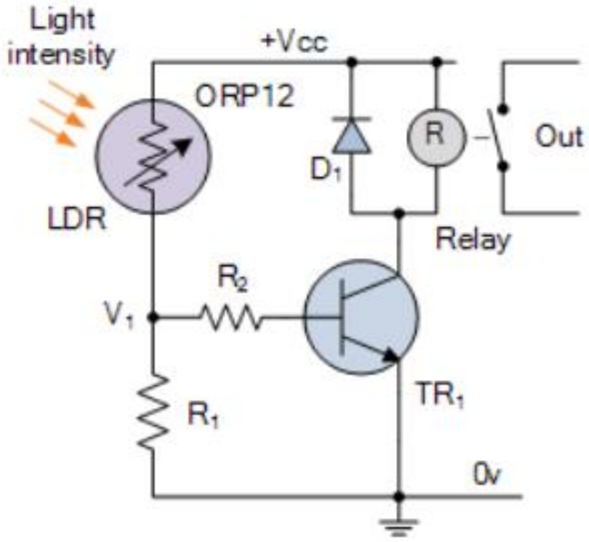
A **Light Sensor** generates an output signal indicating the intensity of light by measuring the radiant energy that exists in a very narrow range of frequencies basically called "light", and which ranges in frequency from "Infra-red" to "Visible" up to "Ultraviolet" light spectrum.

The light sensor is a **passive devices** that convert this "light energy" whether visible or in the infra-red parts of the spectrum into an electrical signal output. Light sensors are more commonly known as "Photoelectric Devices" or "Photo Sensors" because the convert light energy (photons) into electricity (electrons).

- Photo-emissive Cells – These are photodevices which **release free electrons from a light sensitive material** such as caesium when struck by a photon of sufficient energy. The amount of energy the photons have depends on the frequency of the light and the higher the frequency, the more energy the photons have converting light energy into electrical energy.
- Photo-conductive Cells – These photodevices **vary their electrical resistance when subjected to light**. Photoconductivity results from light hitting a semiconductor material which controls the current flow through it. Thus, more light increase the current for a given applied voltage. The most common photoconductive material is Cadmium Sulphide used in LDR photocells.
- Photo-voltaic Cells – These photodevices **generate an emf in proportion to the radiant light energy** received and is similar in effect to photoconductivity. Light energy falls on to two semiconductor materials sandwiched together creating a voltage of approximately 0.5V. The most common photovoltaic material is Selenium used in solar cells.
- Photo-junction Devices – These photodevices are mainly true semiconductor devices such as the photodiode or phototransistor which **use light to control the flow of electrons and holes across their PN-junction**. Photojunction devices are specifically designed for detector application and light penetration with their spectral response tuned to the wavelength of incident light.

The Photoconductive Cell
A **Photoconductive** light sensor does not produce electricity but simply changes its physical properties when subjected to light energy. The most common type of photoconductive device is the *Photoresistor* which changes its electrical resistance in response to changes in the light intensity.
Photoresistors are Semiconductor devices that use light energy to control the flow of electrons, and hence the current flowing through them. The commonly used *Photoconductive Cell* is called the **Light Dependent Resistor** or **LDR**.

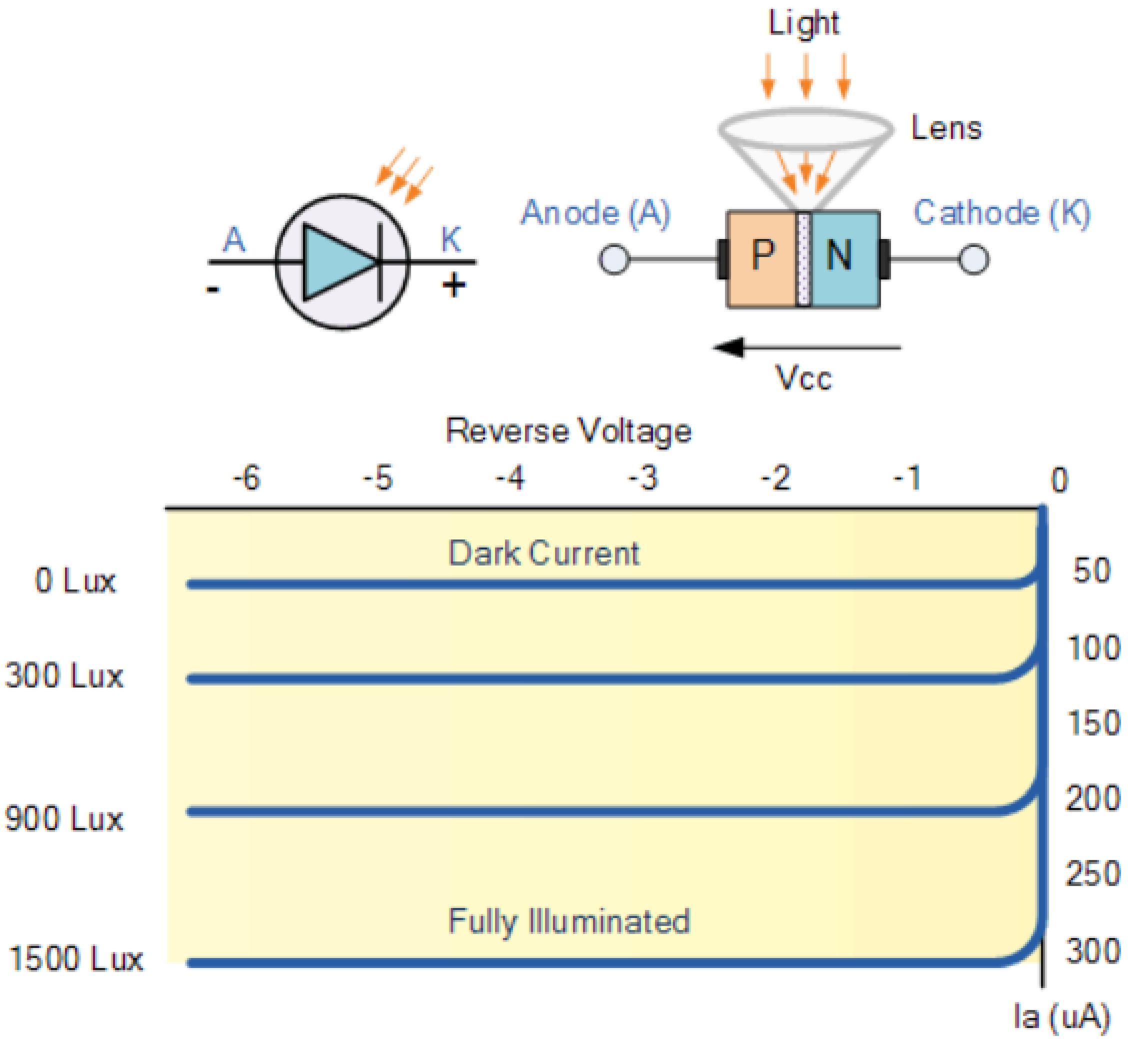
One simple use of a *Light Dependent Resistor*, is as a light sensitive switch as shown below.



LDR Switch

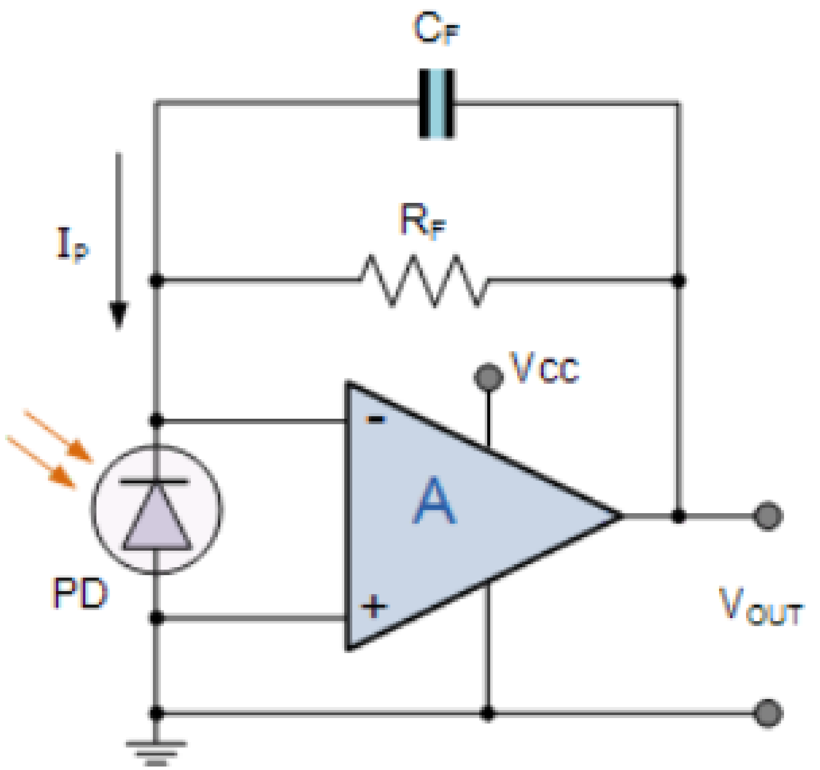
Photojunction Devices
Photojunction Devices are basically PN-Junction light sensors or detectors made from silicon semiconductor PN-junctions which are sensitive to light and which can detect both visible light and infra-red light levels. Photo-junction devices are specifically made for sensing light and this class of photoelectric light sensors include the Photodiode and the Phototransistor.

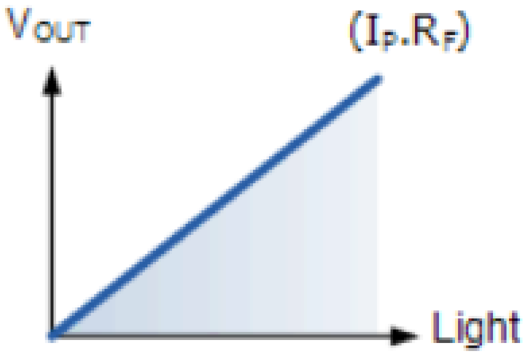
The Photodiode
photo-diode Photo-diode The construction of the Photodiode light sensor is similar to that of a conventional PN-junction diode except that the diodes outer casing is either transparent or has a clear lens to focus the light onto the PN junction for increased sensitivity. The junction will respond to light particularly longer wavelengths such as red and infra-red rather than visible light.



When used as a light sensor, a photodiodes dark current (0 lux) is about 10uA for geranium and 1uA for silicon type diodes. **When light falls upon the junction *more* hole/electron pairs are formed and the leakage current increases. This leakage current increases as the illumination of the junction increases.**

Photo-diode Amplifier Circuit





Photodiodes are very versatile light sensors that can turn its current flow both “ON” and “OFF” in nanoseconds and are commonly used in cameras, light meters, CD and DVD-ROM drives, TV remote controls, scanners, fax machines and copiers etc, and when integrated into operational amplifier circuits as infrared spectrum detectors for fibre optic communications, burglar alarm motion detection circuits and numerous imaging, laser scanning and positioning systems etc.

The Phototransistor

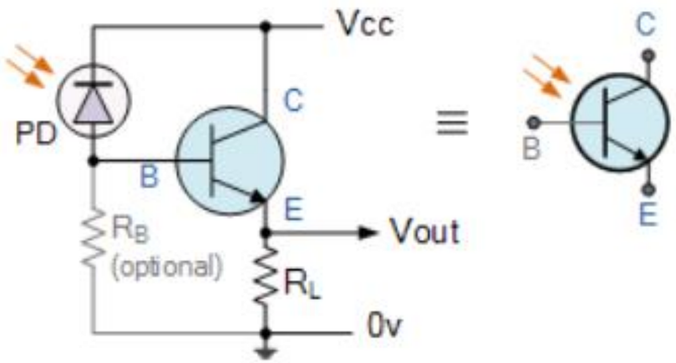
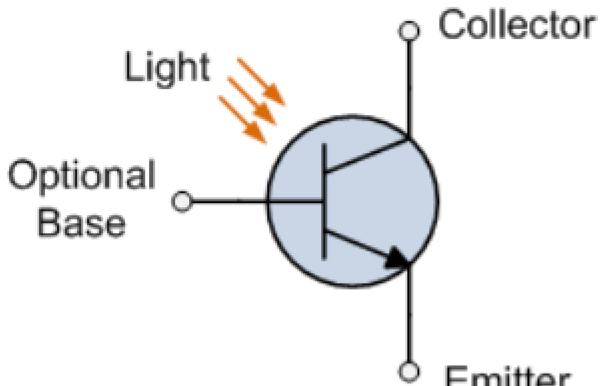
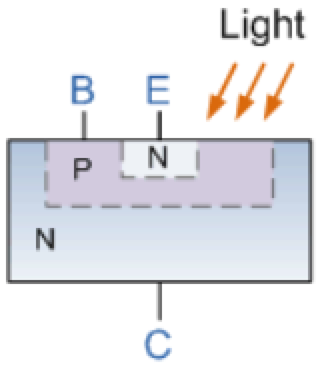
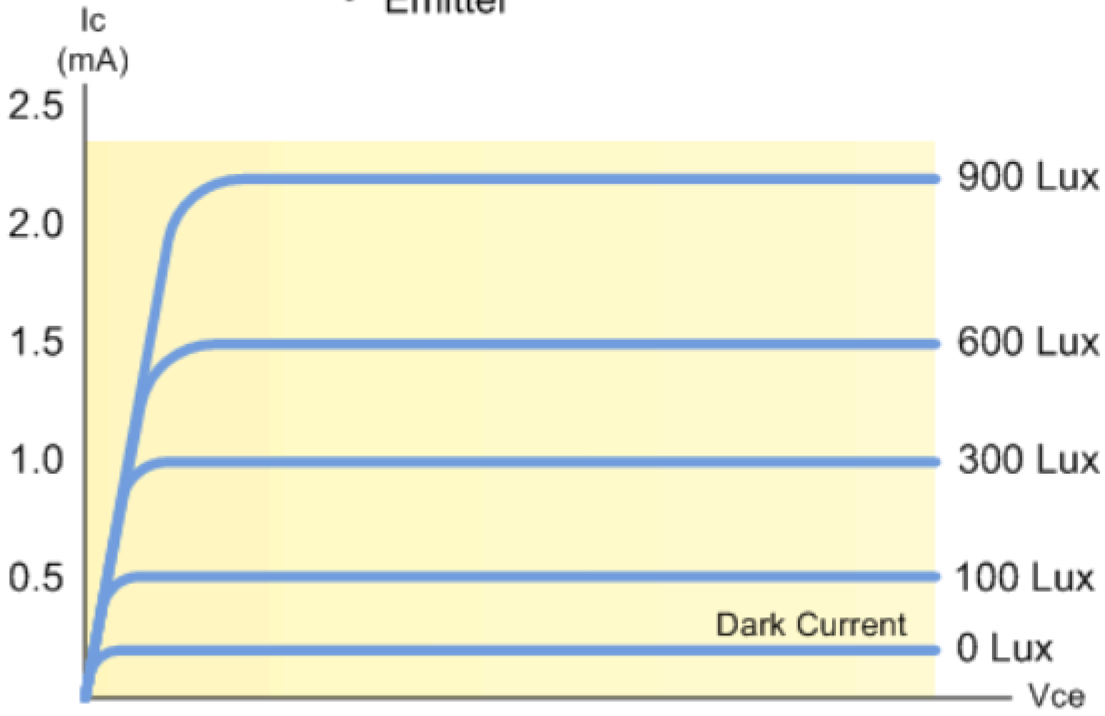


Photo-transistor





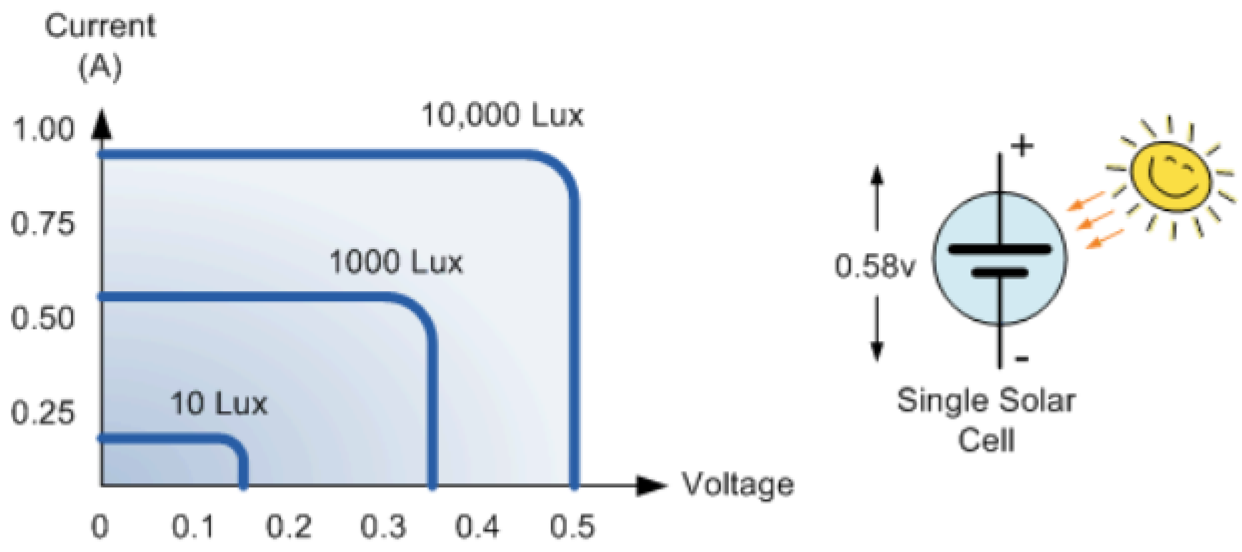


An alternative photo-junction device to the photodiode is the **Phototransistor** which is basically a photodiode with amplification. The Phototransistor light sensor has its collector-base PN-junction reverse biased exposing it to the radiant light source.

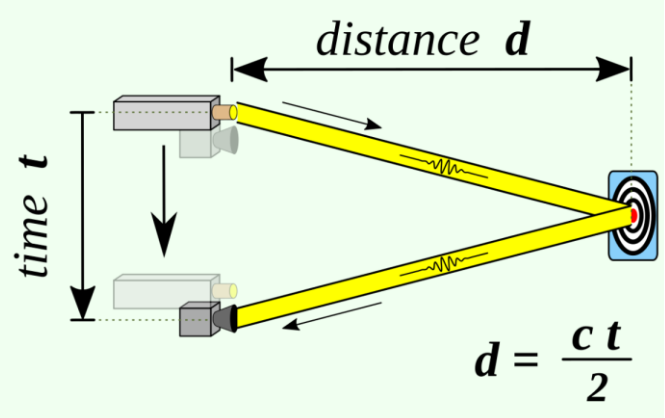
Photovoltaic Cells.
The most common type of photovoltaic light sensor is the **Solar Cell**. Solar cells convert light energy directly into DC electrical energy in the form of a voltage or current to a power a resistive load such as a light, battery or motor. Then photovoltaic cells are similar in many ways to a battery because they supply DC power.

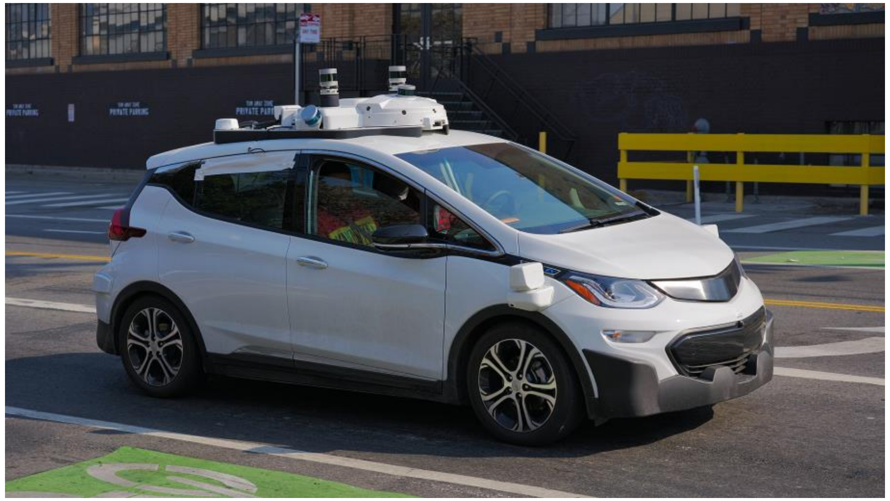
Photovoltaic cells are made from single crystal silicon PN junctions, the same as photodiodes with a very large light sensitive region but are used without the reverse bias. They have the same characteristics as a very large photodiode when in the dark.

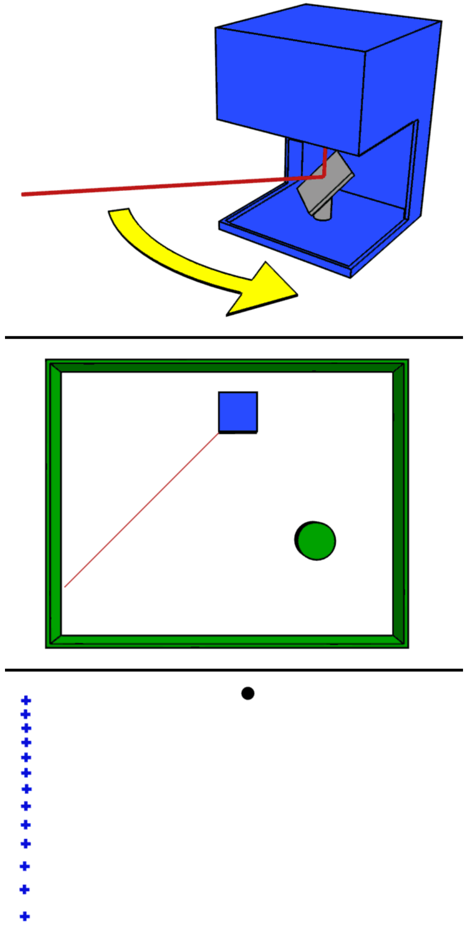
Characteristics of a typical Photovoltaic Solar Cell.



Lidar (Light Detection and Ranging) is a method for measuring distances (ranging) by illuminating the target with laser light and measuring the reflection with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target. It has terrestrial, airborne, and mobile applications.





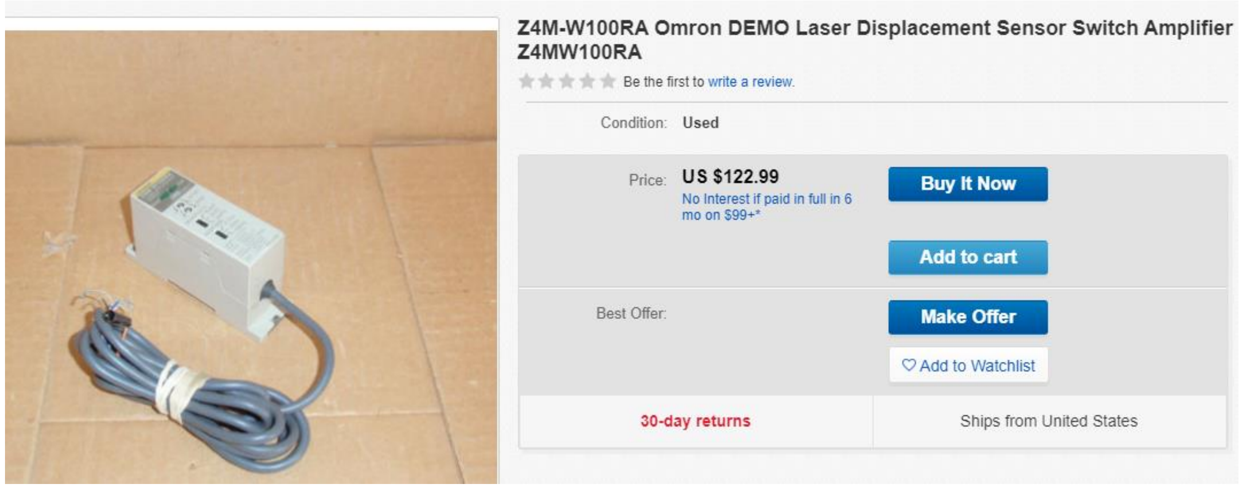


Cruise Automation self-driving car with five Velodyne LiDAR units on the roof.

Spot Dog is a very capable robot that employs a Velodyne lidar sensor to monitor construction sites and document progress.

Police officers use LIDAR to test speed of cars

Industrial Displacement Sensors (laser-based)



- Analog Voltage Output.
- Used ones are available on Ebay.
- Most of the used ones are dis-assembled from assembly lines in the industry
- Resolution: **10 nm**

OMRON Z4M-W40 Displacement Sensor

Brown: 12 to 24 VDC
Blue: 0V (COM)
BLACK: ANALOG OUT (-4Vto4VDC)
ORANGE: ENABLE OUT (40V50mA)
PINK: LASER OFF

Photomultiplier Tubes

A photomultiplier tube, useful for light detection of very weak signals, is a photoemissive device (Dynodes) in which the absorption of a photon results in the emission of an electron. These detectors work by amplifying the electrons generated by a photocathode exposed to a photon flux.

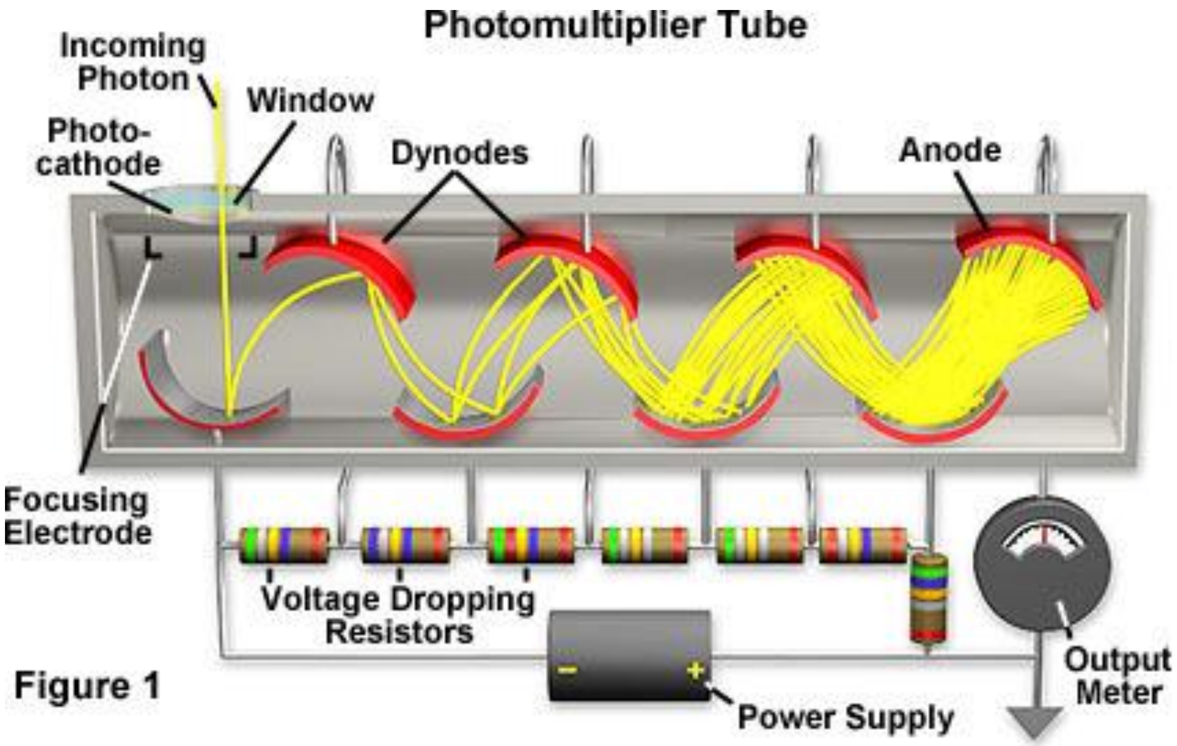
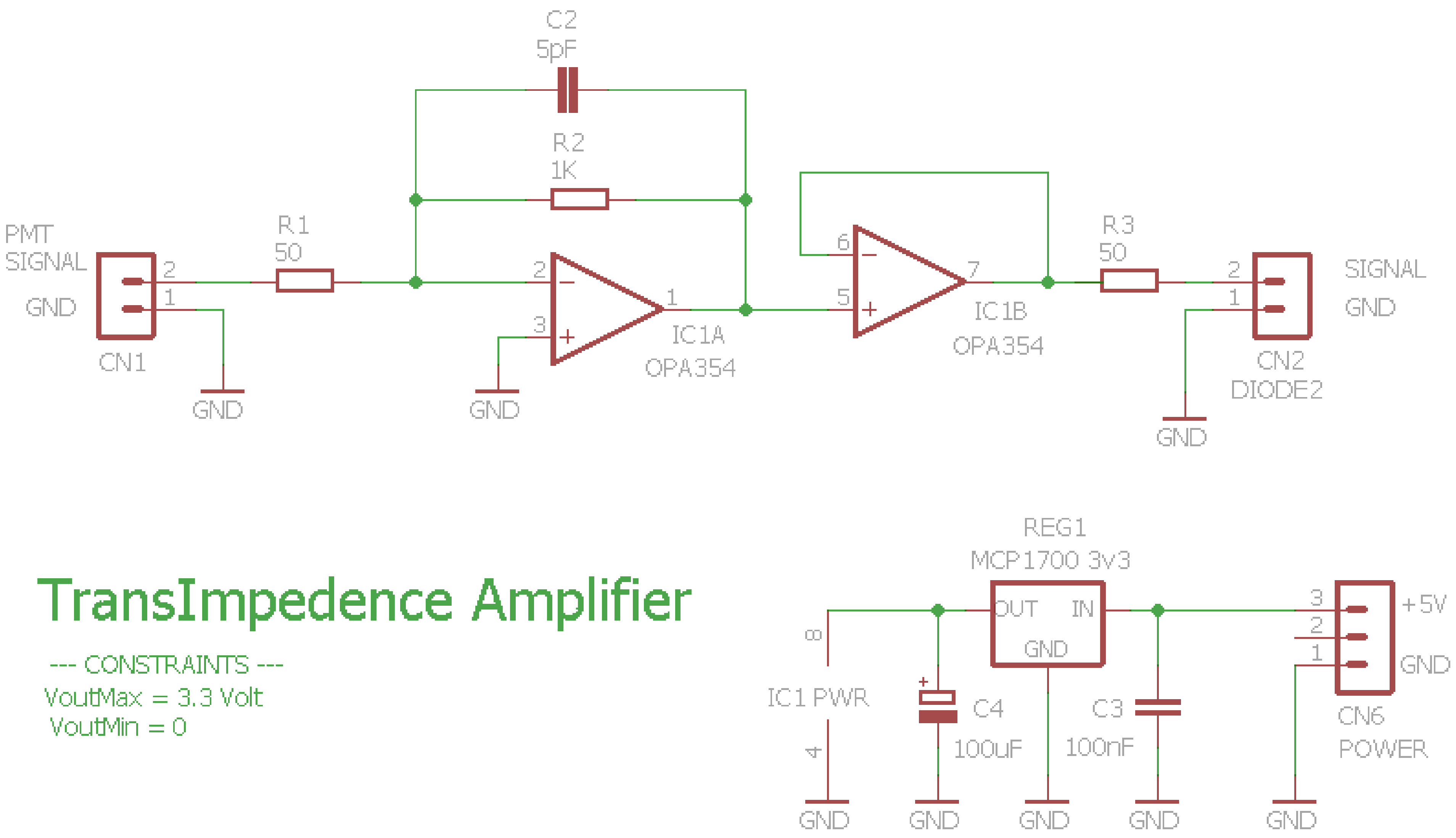


Figure 1

Hamamatsu PMTs

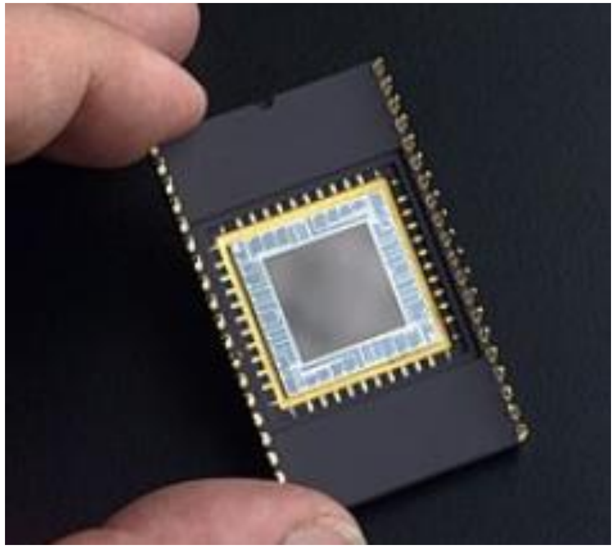
The two PMT products we have: H9306 and H10722

When the output signal from the PMT is current

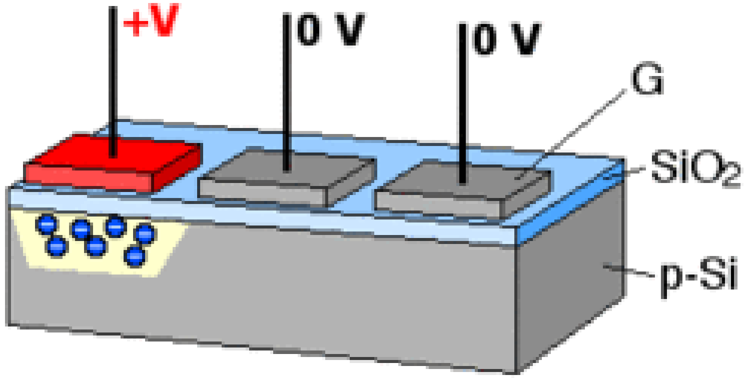


A schematic of a real commercial product

A **charge-coupled device (CCD)** is an integrated circuit containing an array of linked, or coupled, capacitors. Under the control of an external circuit, each capacitor can transfer its electric charge to a neighboring capacitor. CCD sensors are a major technology used in digital imaging. In a CCD image sensor, pixels are represented by p-doped metal–oxide–semiconductor (MOS) capacitors. These MOS capacitors, the basic building blocks of a CCD are biased above the threshold for inversion when image acquisition begins, allowing the conversion of incoming photons into electron charges at the semiconductor-oxide interface; the CCD is then used to read out these charges. Although CCDs are not the only technology to allow for light detection, CCD image sensors are widely used in professional, medical, and scientific applications where high-quality image data are required. In applications with less exacting quality demands, such as consumer and professional digital cameras, active pixel sensors, also known as CMOS sensors (complementary MOS sensors), are generally used. However, the large quality advantage CCDs enjoyed early on has narrowed over time.

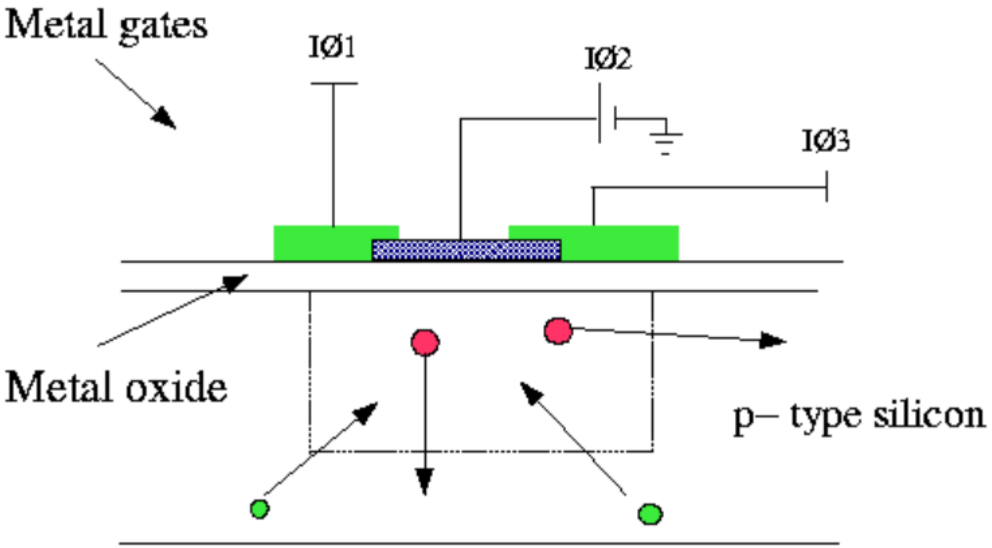


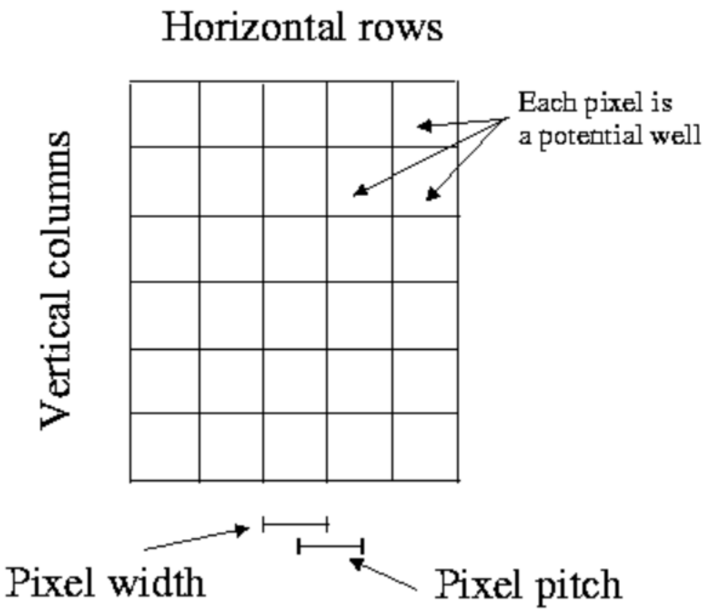
A specially developed CCD in a wire-bonded package used for ultraviolet imaging

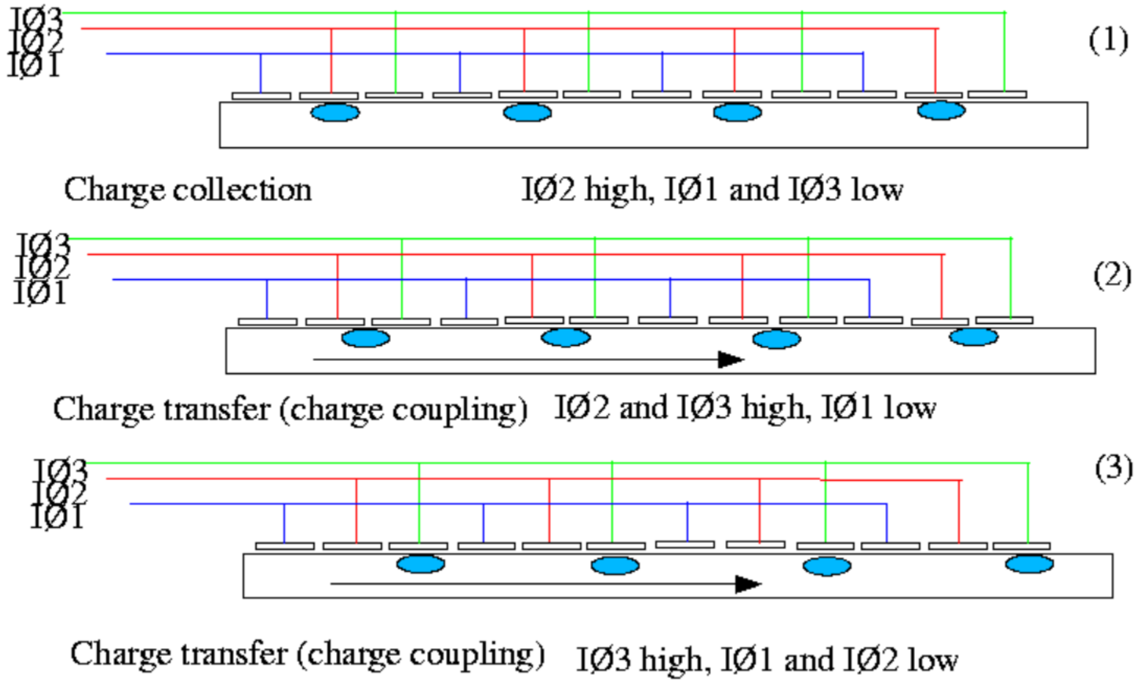


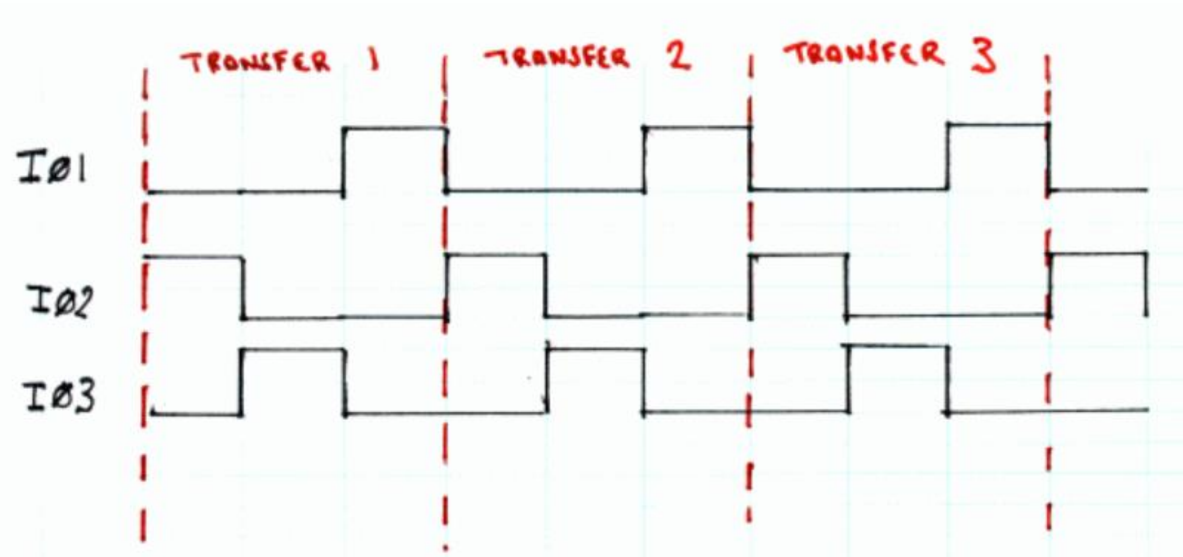
The charge packets (electrons, blue) are collected in potential wells (yellow) created by applying positive voltage at the gate electrodes (G). Applying positive voltage to the gate electrode in the correct sequence transfers the charge packets.

CCD Operation



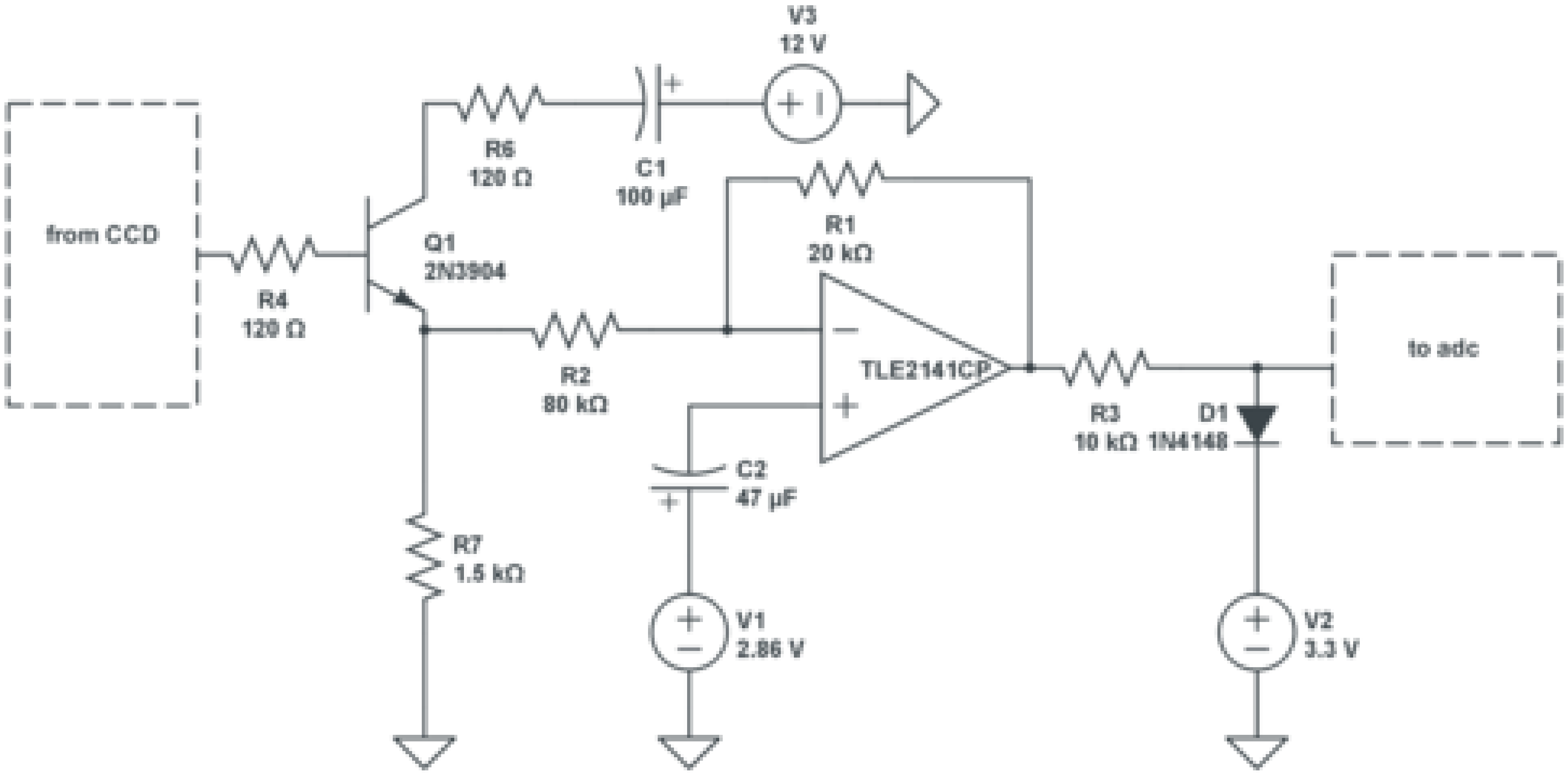




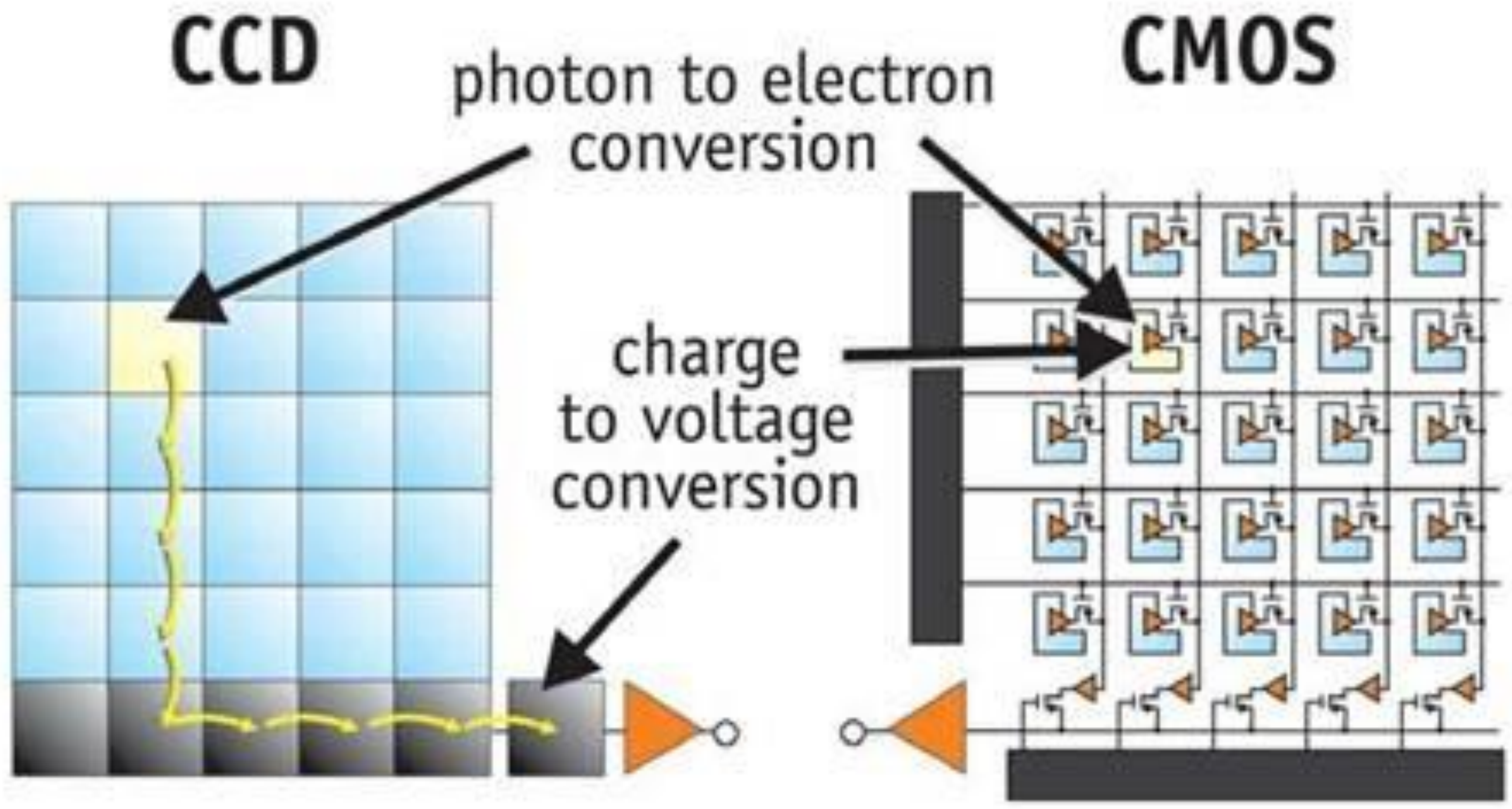


https://www.mssl.ucl.ac.uk/www_detector/ccdgroup/optheory/ccdoperation.html

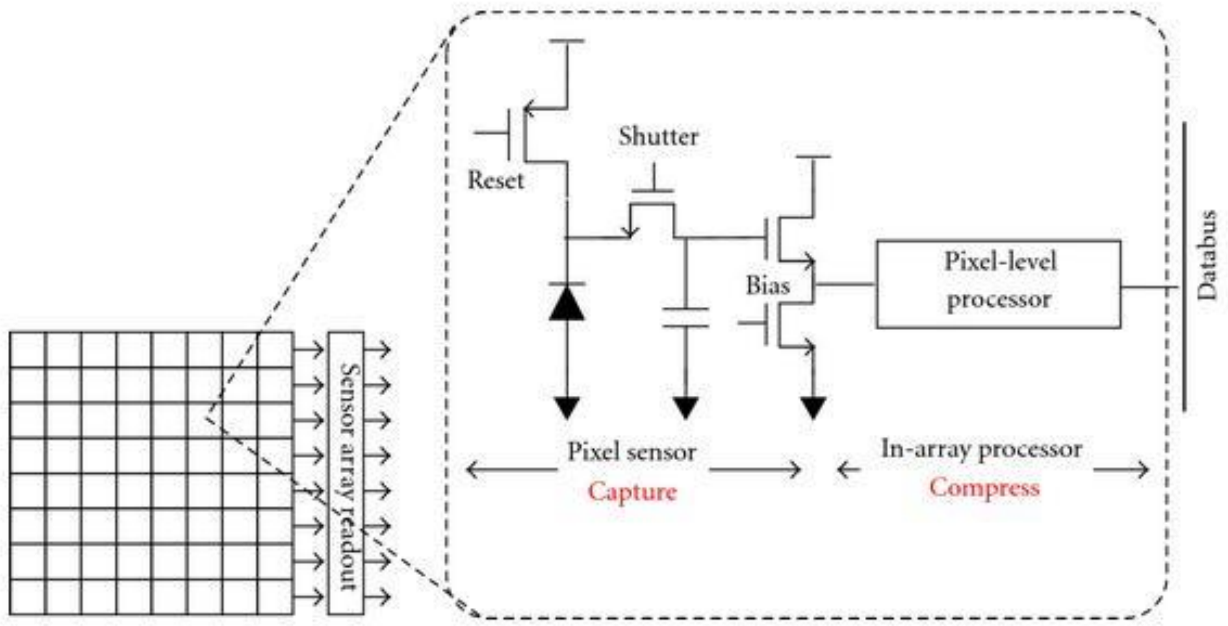
CCD Read Out Circuit

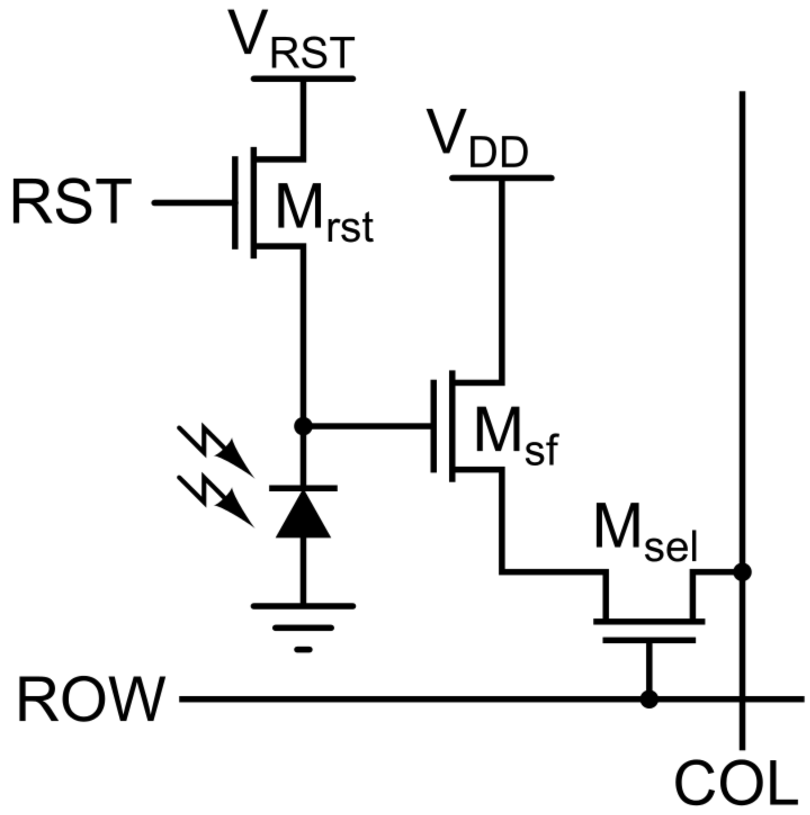


CMOS imagers dominate the low-cost consumer electronics space, whereas CCDs still provide exceptional image quality but at the cost of speed. There are several important image sensor specifications to consider. The number of pixels captured is typically given in megapixels. Pixel counts can range dramatically from sensor to sensor. Pixel size refers to the area on the sensor dedicated to each pixel. Larger pixel areas can receive more photons and therefore typically provide cleaner, less noisy images.



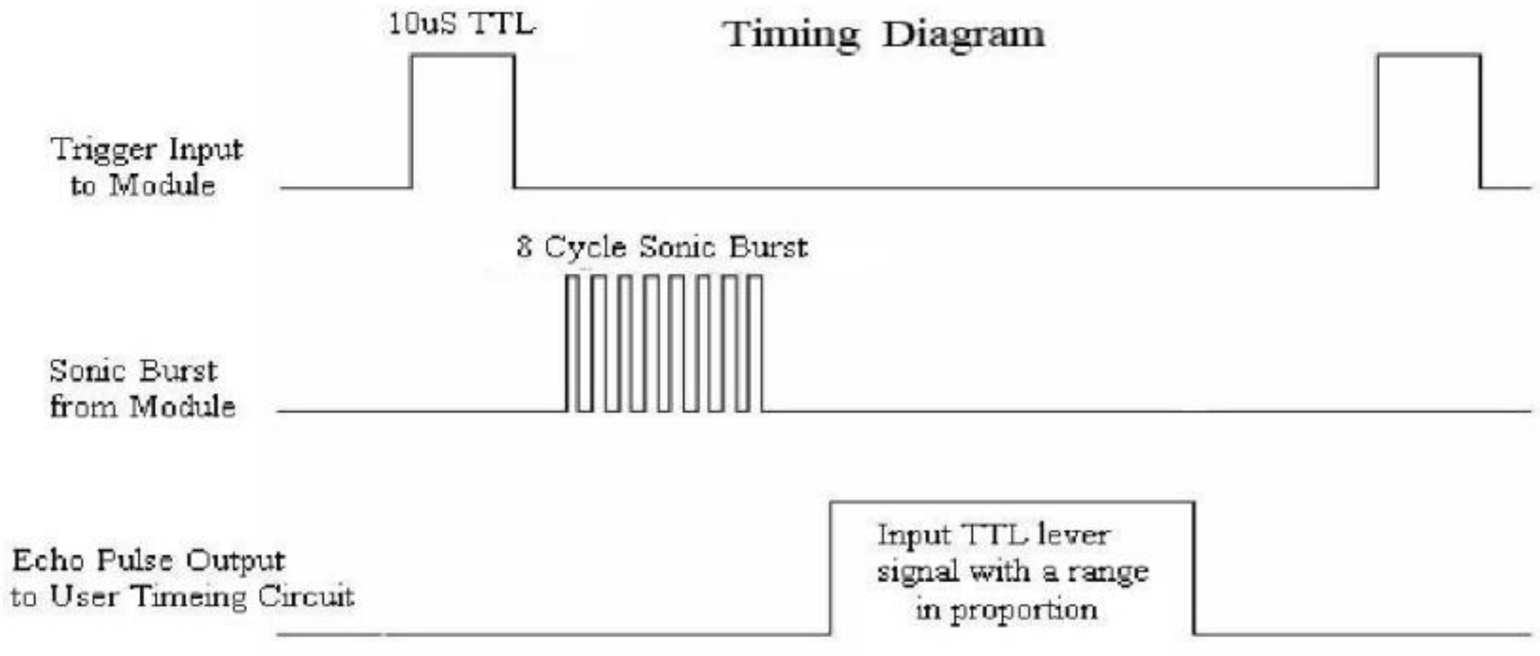
CMOS imagers – how it works?





Sound

The **HC-SR04 ultrasonic sensor** uses SONAR (**sound navigation ranging**) to determine the distance of an object just like the bats do. It offers excellent non-contact range detection with high accuracy and stable readings in an easy-to-use package from **2 cm to 400 cm** or 1” to 13 feet. The operation is not affected by sunlight or black material, although acoustically, **soft materials like cloth can be difficult to detect**. It comes complete with ultrasonic transmitter and receiver module.



```
// Arduino Code with the HC-SR04 Library

#include "SR04.h“
#define TRIG_PIN A5
#define ECHO_PIN A4 SR04 sr04 = SR04(ECHO_PIN,TRIG_PIN);
long a;

void setup()
{
	Serial.begin(9600);
	delay(1000);
}

void loop()
{
	a=sr04.Distance();
	Serial.print(a);
	Serial.println("cm");
	delay(1000);
}
```

```
// Arduino Code without the HC-SR04 Library

const int trigPin = 9;
const int echoPin = 10;
float duration, distance;
void setup()
{
        pinMode(trigPin, OUTPUT);
        pinMode(echoPin, INPUT);
        Serial.begin(9600);
}
void loop()
{
        digitalWrite(trigPin, LOW);
        delayMicroseconds(2);
        digitalWrite(trigPin, HIGH);  // rising edge to trigger the sonic burst
        delayMicroseconds(10);
        digitalWrite(trigPin, LOW);   // turn off the sonic bust
        duration = pulseIn(echoPin, HIGH);  // the pulseIn() function
        distance = (duration*.0343)/2;  // why 0.0343?
        Serial.print("Distance: ");
         Serial.println(distance);
        delay(100);
}
```

The pulseIn() function:

Reads a pulse (either HIGH or LOW) on a pin. For example, if value is HIGH, pulseIn() waits for the pin to go from LOW to HIGH, starts timing, then waits for the pin to go LOW and stops timing. Returns the length of the pulse in **microseconds** or gives up and returns 0 if no complete pulse was received within the timeout.

Distance in cm:

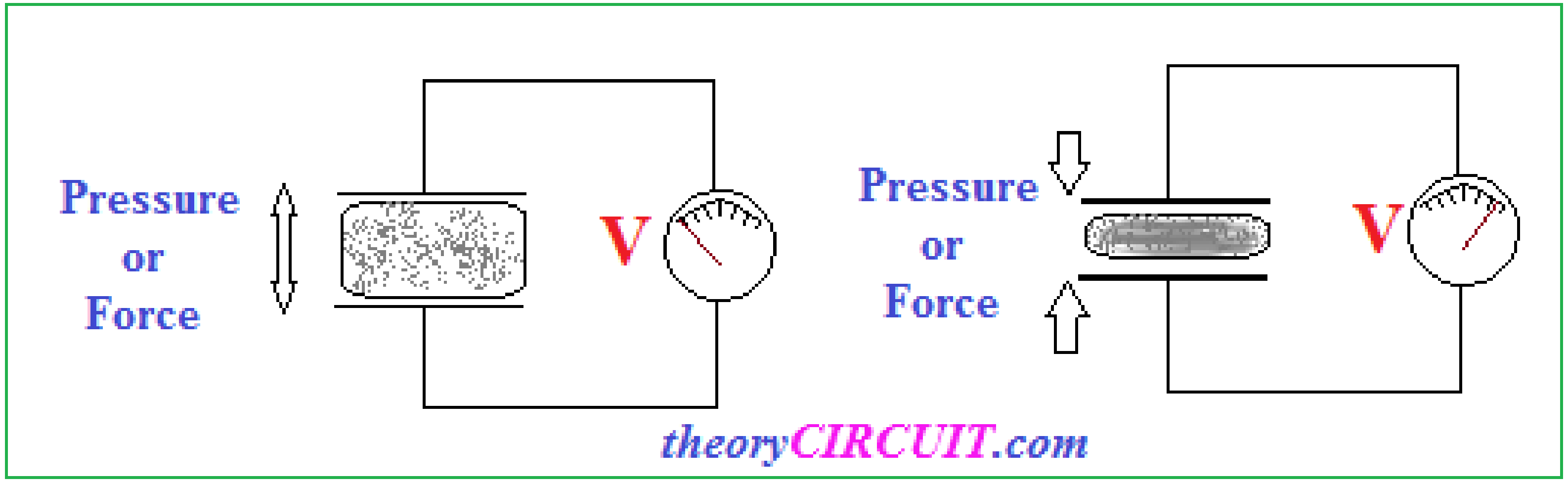
((Duration*10^-6)/2)*343m/s * 100

=Duration*0.0343/2

Piezoelectric pressure transducer working principle

Pizo sensor or Vibration sensor is made by the piezo element, this is uses the piezo electric effect. The Piezo Electric sensor element is a transducer which converts Pressure, Force, Strain some times Temperature into Electrical Charge.

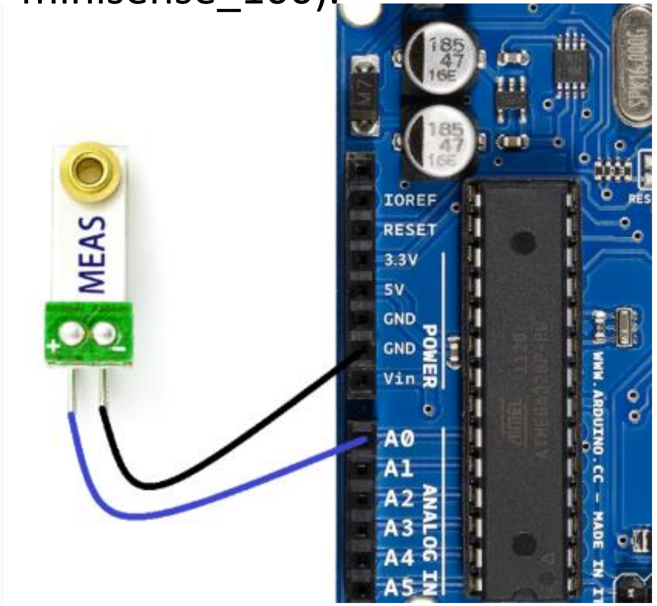
You may heard about Buzzer (Piezo alarm device) that is also uses the piezo element, when we apply electric charge this element gets vibration at different frequency range (depends on the size of piezo material) so that it gives buzzer beep sound. For the both transducer and buzzer, piezo element is placed between two metal plates. the illustration represents working principle of piezo element when the pressure applied electric charge induced in piezo elements and that is measured through the voltmeter.



MiniSense 100 Vibration Sensor: it measures pressure but can be used as a vibration sensor. The inertia of the mass and the acceleration produce pressure to the sensor and therefore produce voltage output.

FEATURES

- High Voltage Sensitivity (1 V/g)
(g is Gravitational constant not gram)
- Over 5 V/g at Resonance
- Horizontal or Vertical Mounting
- Shielded Construction
- Solderable Pins, PCB Mounting
- Low Cost
- < 1% Linearity
- Up to 40 Hz (2,400 rpm)
Operation Below
Resonance   (Source Datasheet minisense_100).

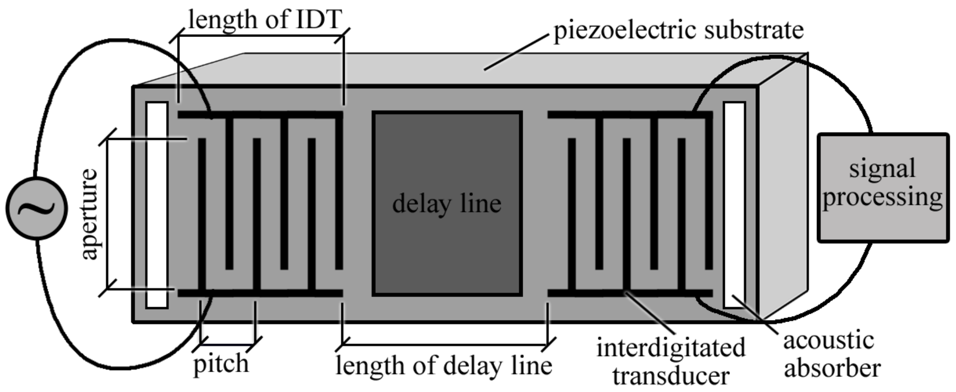



```
void loop()
{
      int reading= analogRead(piezo_Pin);
      Serial.println(reading);
      if (reading > threshold)
            {
                  digitalWrite(LED_Pin, HIGH);
                  delay(1000);
                  digitalWrite(LED_Pin, LOW);
            }
}
```

Applications:

- Washing Machine Load Imbalance
- Vehicle Motion Sensor
- Anti-Theft Devices
- Vital Signs Monitoring
- Tamper Detection
- Impact Sensing

Surface acoustic wave sensors (SAW) are a class of microelectromechanical systems (MEMS) which rely on the modulation of surface acoustic waves to sense a physical phenomenon. The sensor transduces an input electrical signal into a mechanical wave which, unlike an electrical signal, can be easily influenced by physical phenomena. The device then transduces this wave back into an electrical signal. Changes in amplitude, phase, frequency, or time-delay between the input and output electrical signals can be used to measure the presence of the desired phenomenon.



Surface Acoustic Wave Sensor
Interdigitated Transducer Diagram

A Commercial SAW Device

A SAW sensor consists of a piezoelectric substrate that has an interdigital electrode lithographically patterned on its surface. The surface of the SAW sensor has a polymer coating that offers solubility to fuel vapors. The mechanism of detection is a reversible absorption of the fuel component into the polymer. When this device is excited by external RF (Radio Frequency) voltage, a Rayleigh wave (waves perpendicular to the surface) generates on the surface of the device. When fuel contamination comes in contact with the SAW sensor surface it will absorb into the polymer coating.
This absorption into the polymer causes a mass change, producing a corresponding change in the amplitude and velocity of the surface wave. When used in a self resonant oscillator circuit, the change in Rayleigh wave velocity resulting from vapor absorption into the polymer coating causes a corresponding change in oscillator frequency. This change in frequency is the basis of the Fuel Sniffer's detection. The absorption is semi-selective based on the properties of the polymer coating and the partition coefficient (solubility of the chemical and polymer) of the chemical of interest.

Capacitive Sensors

24-Bit **Capacitance-to-Digital Converter** with Temperature Sensor AD7745/AD7746

FEATURES Capacitance-to-digital converter New standard in single chip solutions Interfaces to single or differential floating sensors Resolution down to 4 aF (that is, up to 21 ENOB) Accuracy**: 4 fF** Linearity: 0.01% Common-mode (not changing) capacitance up to 17 pF Full-scale (changing) capacitance range: ±4 pF Tolerant of parasitic capacitance to ground up to 60 pF Update rate: 10 Hz to 90 Hz Simultaneous 50 Hz and 60 Hz rejection at 16 Hz Temperature sensor on-chip Resolution: 0.1°C, accuracy: ±2°C Voltage input channel Internal clock oscillator 2-wire serial interface (**I2C**®-compatible) Power 2.7 V to 5.25 V single-supply operation 0.7 mA current consumption Operating temperature: –40°C to +125°C 16-lead TSSOP package APPLICATIONS Automotive, industrial, and medical systems for Pressure measurement Position sensing Level sensing Flowmeters Humidity sensing Impurity detection

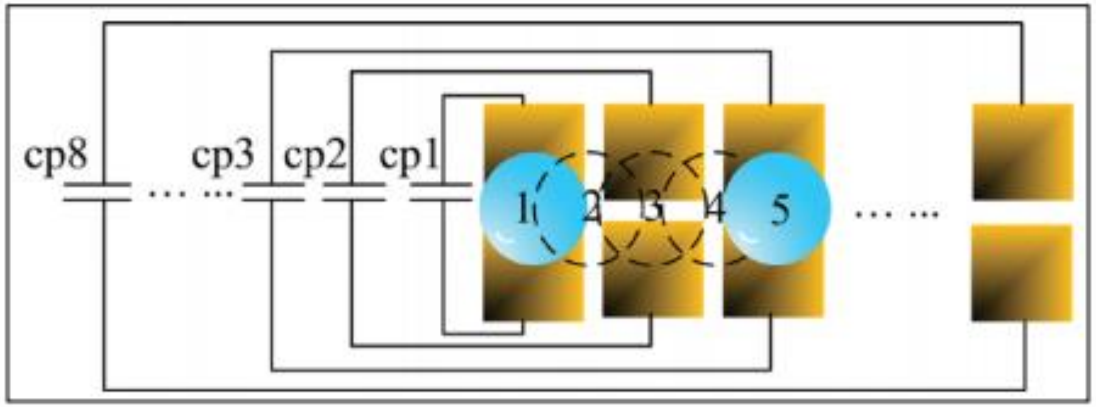
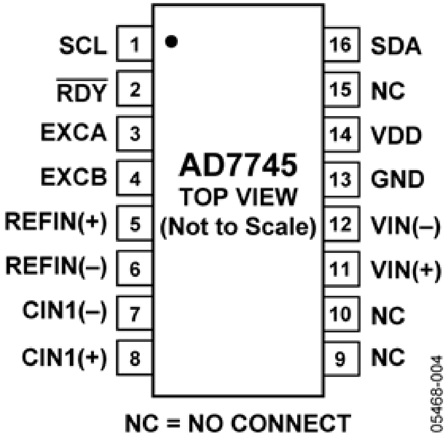


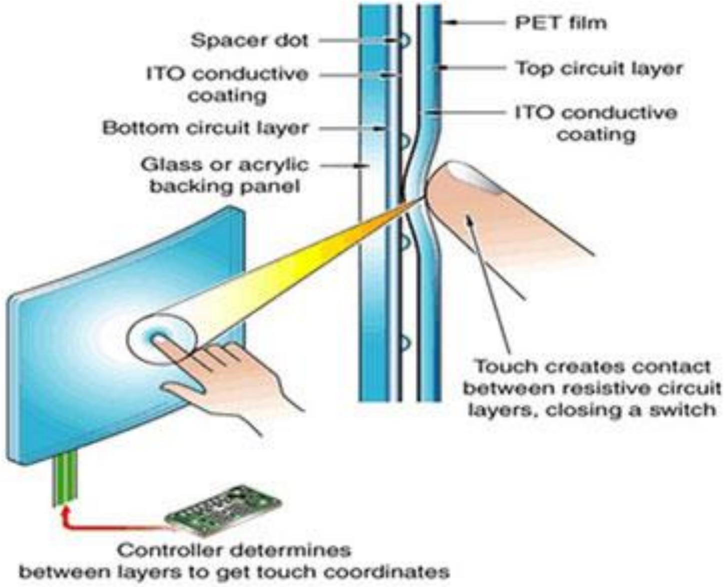
Diagram of the capacitance of each electrode pair. The five droplets in this figure are specifically used to represent the five different positions of the droplets on the first three electrode pairs [1].

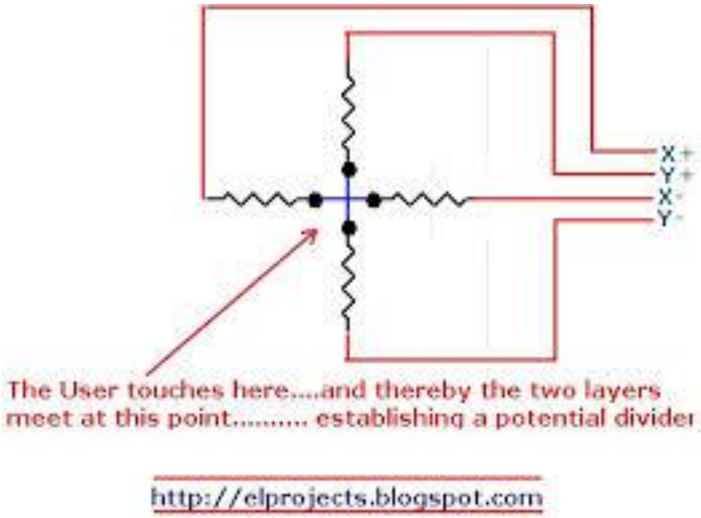


[1] Y. Li, H. Li and R. Jacob Baker. A low-cost and high-resolution droplet position detector for an intelligent electrowetting on dielectric device. Journal of Laboratory Automation 20 (2015) 663-669.

Touch Sensors

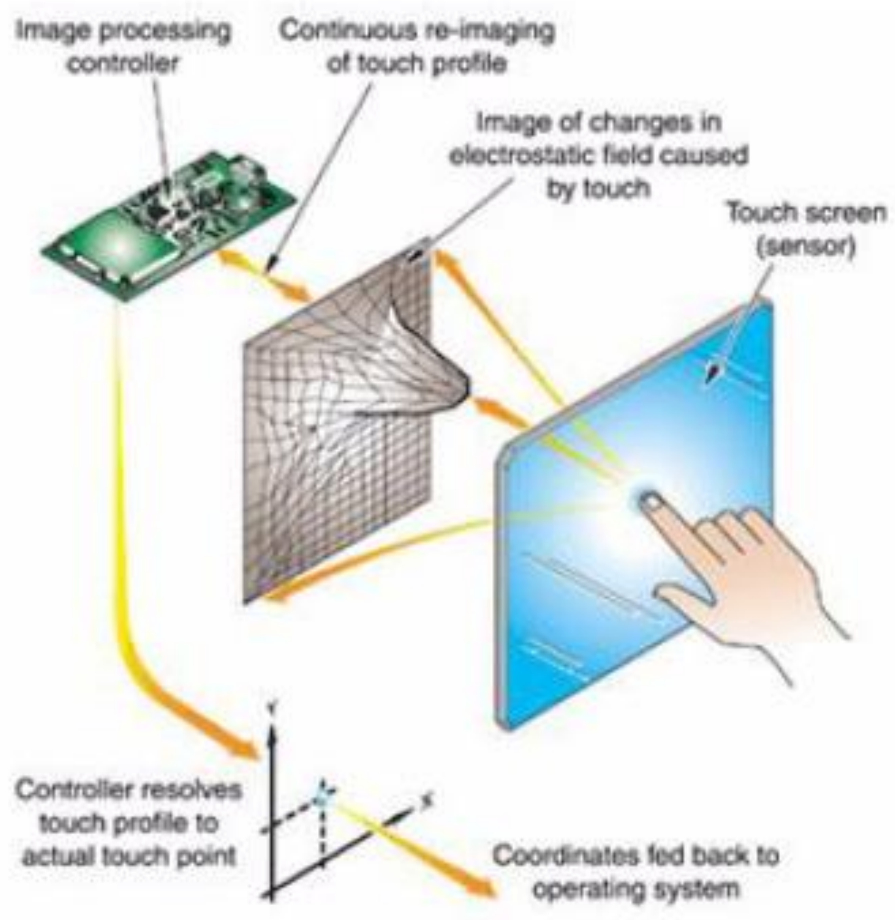
Resistive: A resistive touch screen panel is coated with a thin metallic electrically conductive and resistive layer that causes a **change in the electrical current** which is registered as a touch event and sent to the controller for processing. Resistive touch screen panels are generally more affordable but offer only 75% clarity and the layer can be damaged by sharp objects. Resistive touch screen panels are not affected by outside elements such as dust or water.





Old Garmin GPS touchscreens are resistive panels. Gently tapping using your finger won't work. Instead, using your nail or a stylus pen.

Capacitive: A capacitive touch screen panel is coated with a material that stores electrical charges. When the panel is touched, **a small amount of charge is drawn to the point of contact**. Circuits located at each corner of the panel measure the charge and send the information to the controller for processing. Capacitive touch screen panels must be touched with a finger unlike resistive and surface wave panels that can use fingers and stylus. Capacitive touch screens are not affected by outside elements and have high clarity.

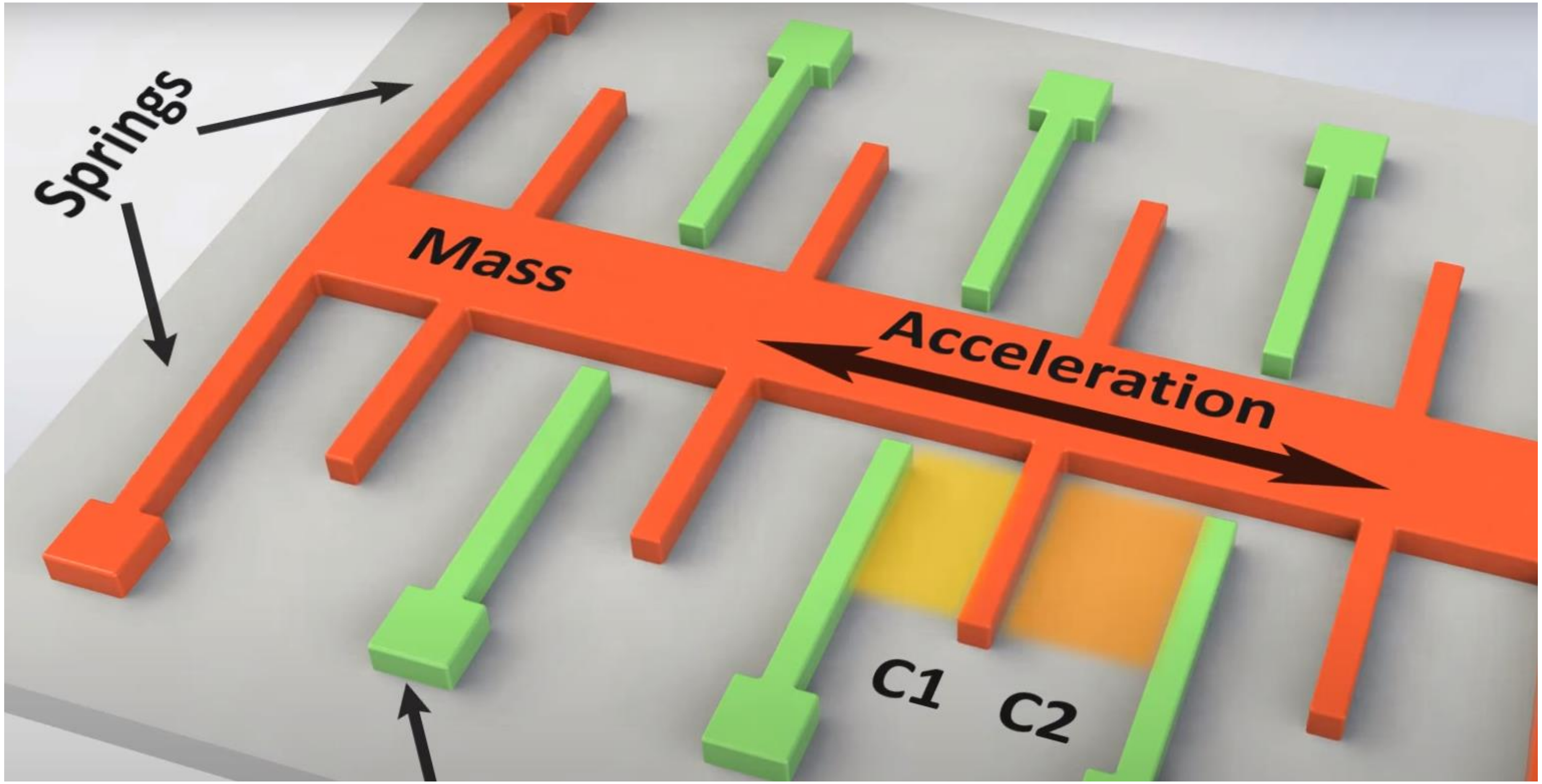


Basic principles of a capacitive touch screen.

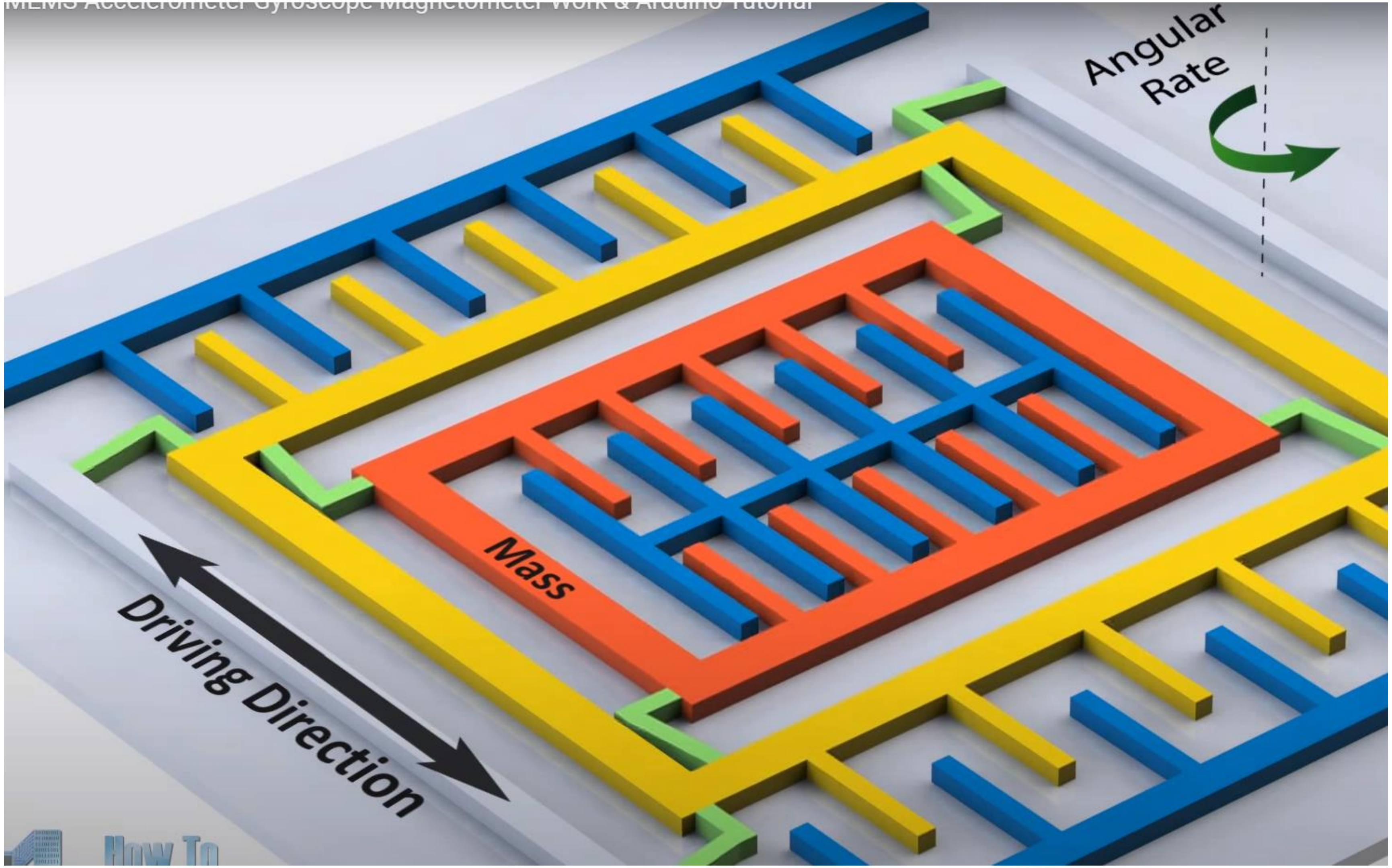
Most of the smart phones use capacitive touchscreens.

Accelerometers/Gyroscope

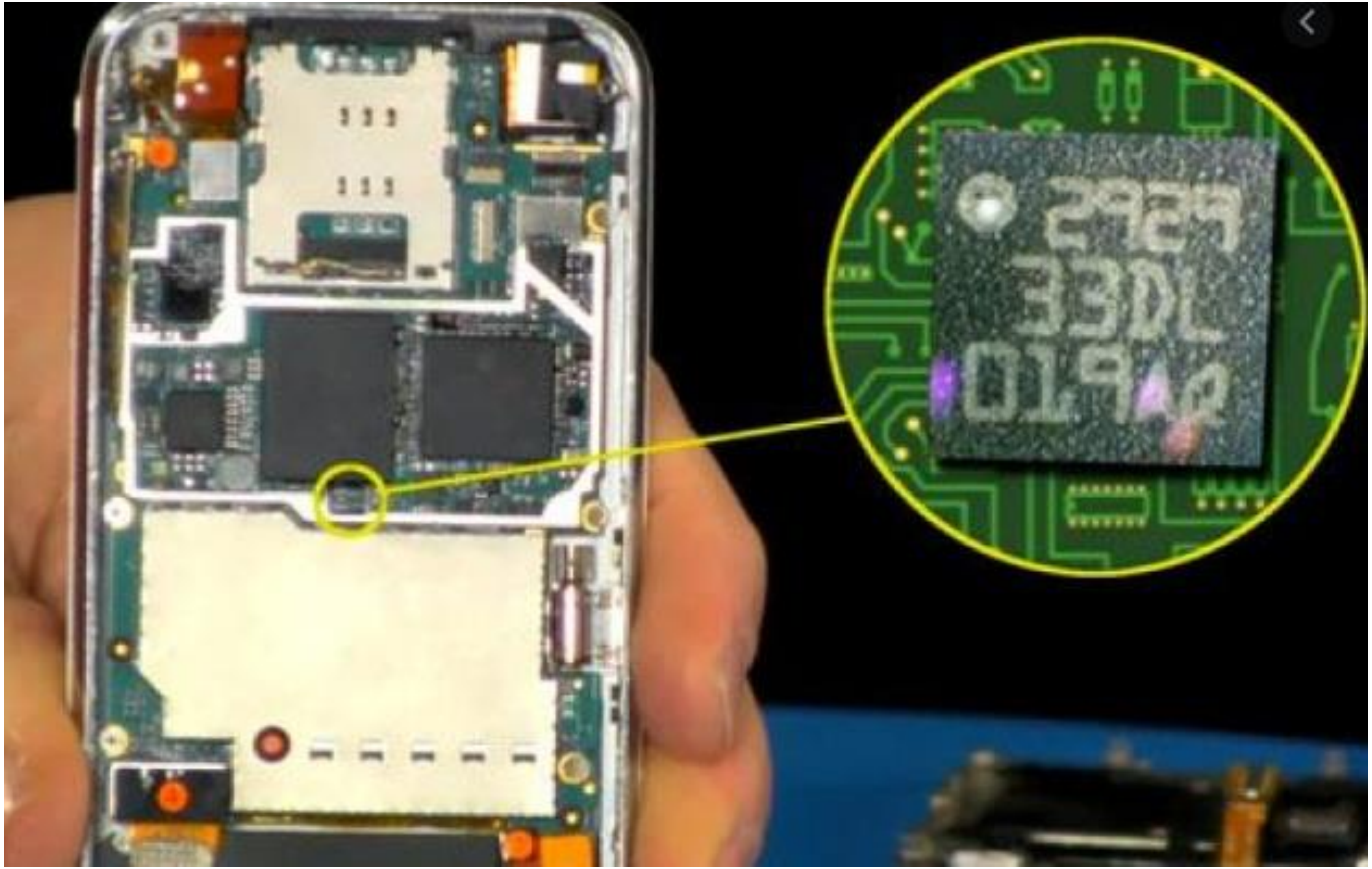
The **MPU-60X0** is the world's first integrated 6-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP) all in a small 4x4x0.9mm package. With its dedicated **I2C** sensor bus, it directly accepts inputs from an external 3-axis compass to provide a complete 9-axis MotionFusion™ output.



MEMs Gyroscope (MPU6050)



An Accelerometer in a Smart Phone

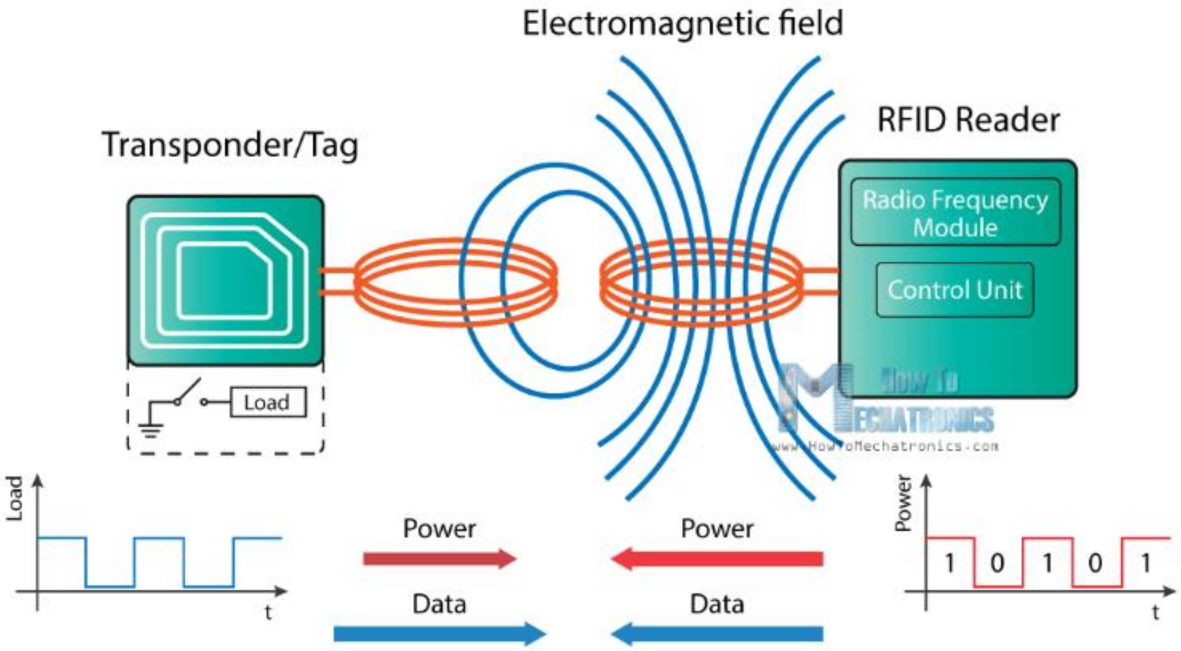


RFID (Radio-Frequency Identification)

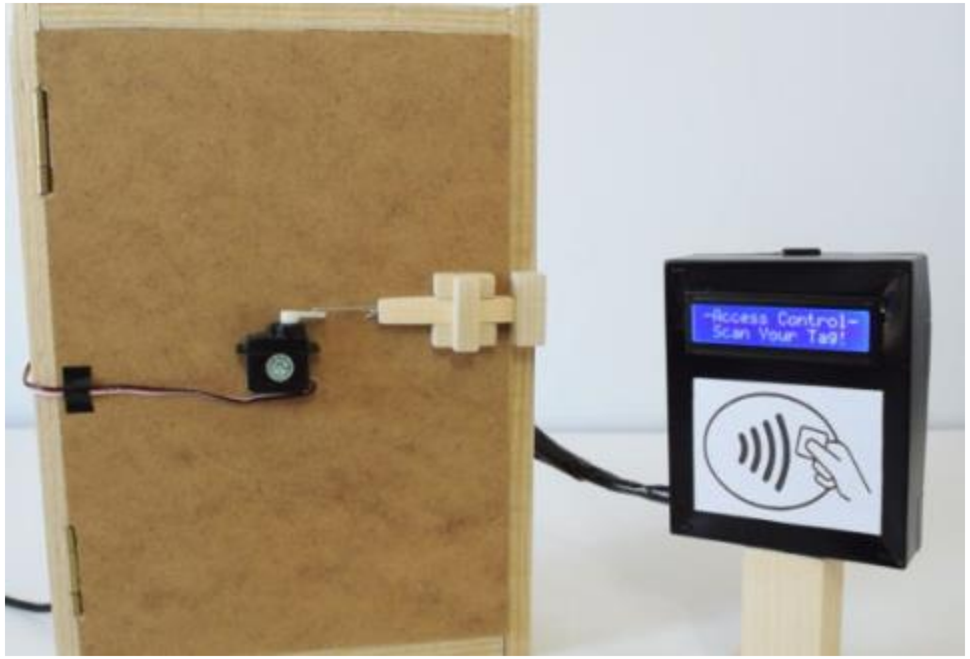
An RFID system consists of two main components, a transponder or a tag which is located on the object that we want to be identified, and a transceiver or a reader.

The RFID reader consist of a radio frequency module, a control unit and an antenna coil which generates high frequency electromagnetic field. On the other hand, the tag is usually a passive component, which consist of just an antenna and an electronic microchip, so when it gets near the electromagnetic field of the transceiver, due to induction, a voltage is generated in its antenna coil and this voltage **serves as power for the microchip.**

Now as the tag is powered it can extract the transmitted message from the reader, and for sending message back to the reader, it uses a technique called load manipulation. Switching on and off a load at the antenna of the tag will affect the power consumption of the reader's antenna which can be measured as voltage drop. This changes in the voltage will be captured as ones and zeros and that's the way the data is transferred from the tag to the reader.

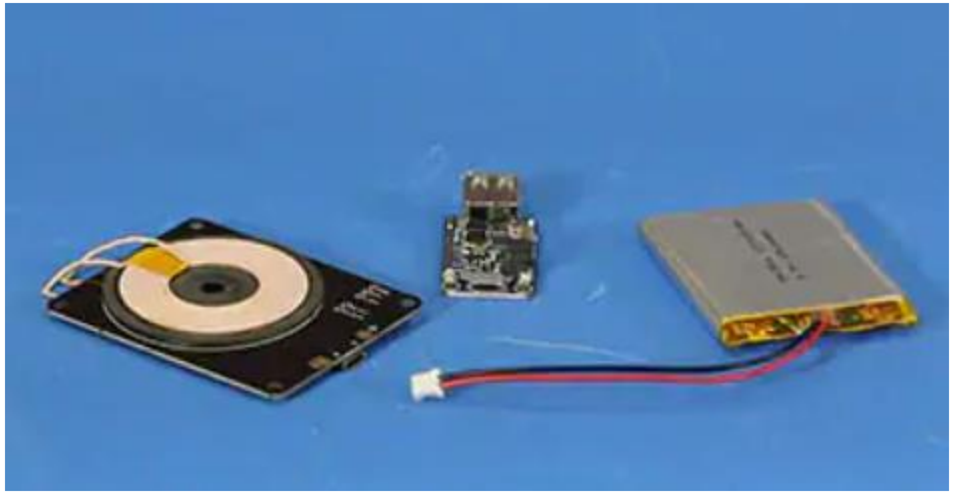


MFRC522 RFID Module - An RFID kit you can play with at home
https://howtomechatronics.com/tutorials/arduino/rfid-works-make-arduino-based-rfid-door-lock/



A Hotel Door project. You can even program the ID of the card

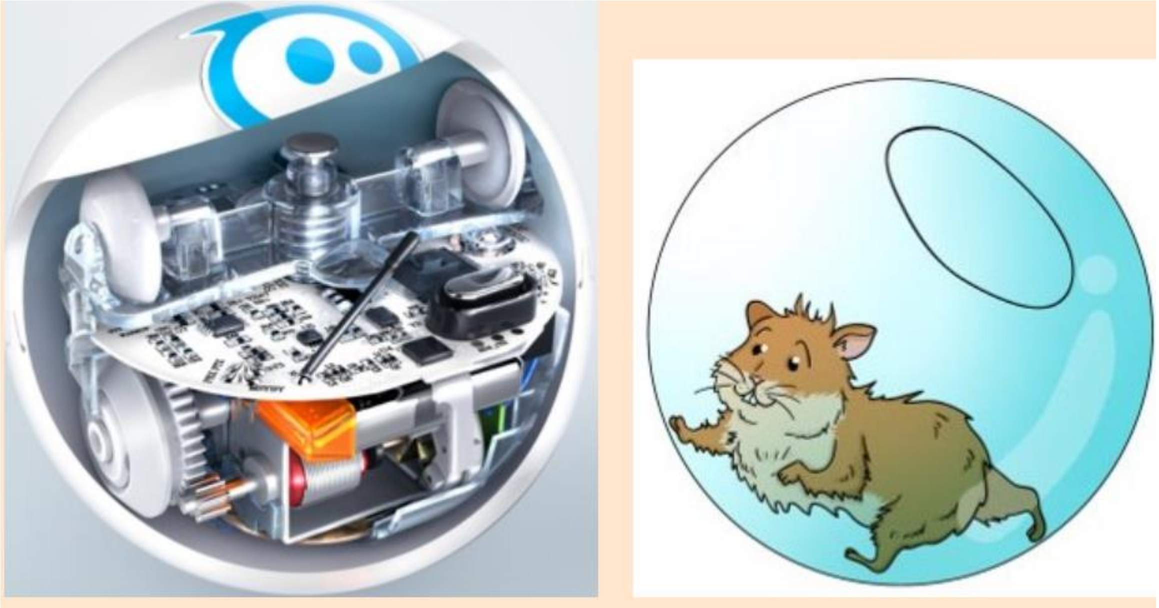
Wireless charger



1901

Datashe

Digi-Key Part Number	1528-1384-ND
Manufacturer	Adafruit Industries LLC
Manufacturer Part Number	1901
Description	UNIVERSAL QI WIRELSS RECEIVR MOD
Detailed Description	BQ51013B Wireless Power Supply/Charging Power Management Evaluation Board



The Sphero Bolt Robot