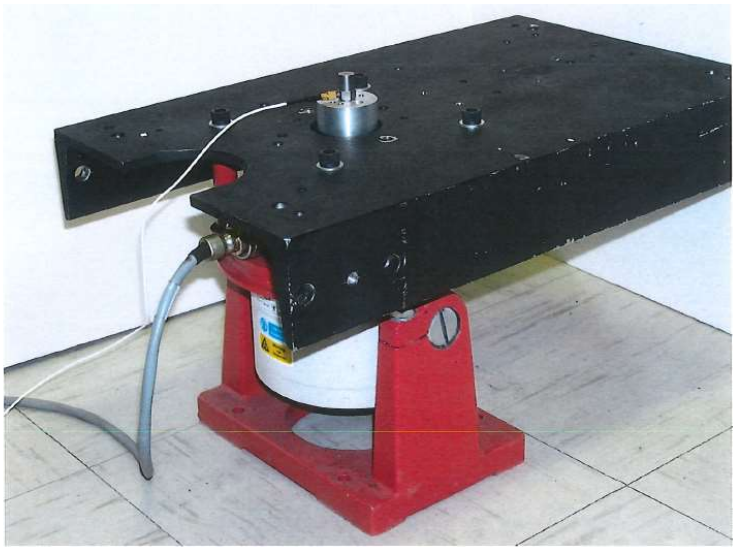
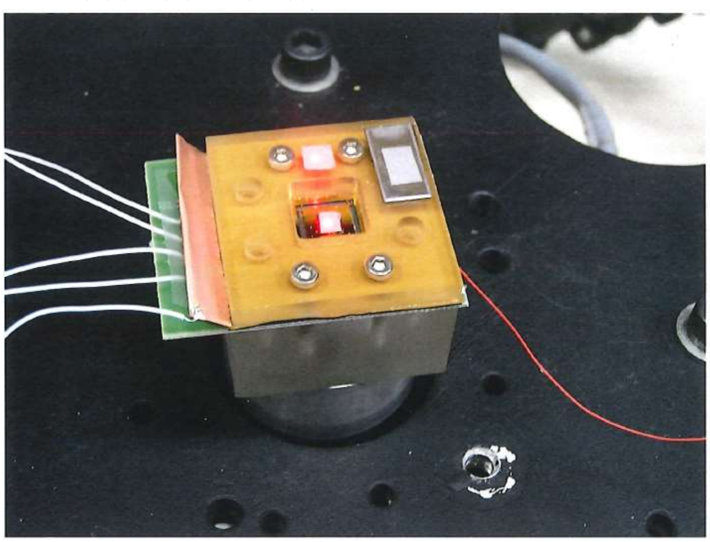
Measuring Transmissibility

This is an electromagnetic shaker. Applying a time-varying voltage results in the center shaft moving up and down with that frequency content and with a displacement proportional to the voltage level.



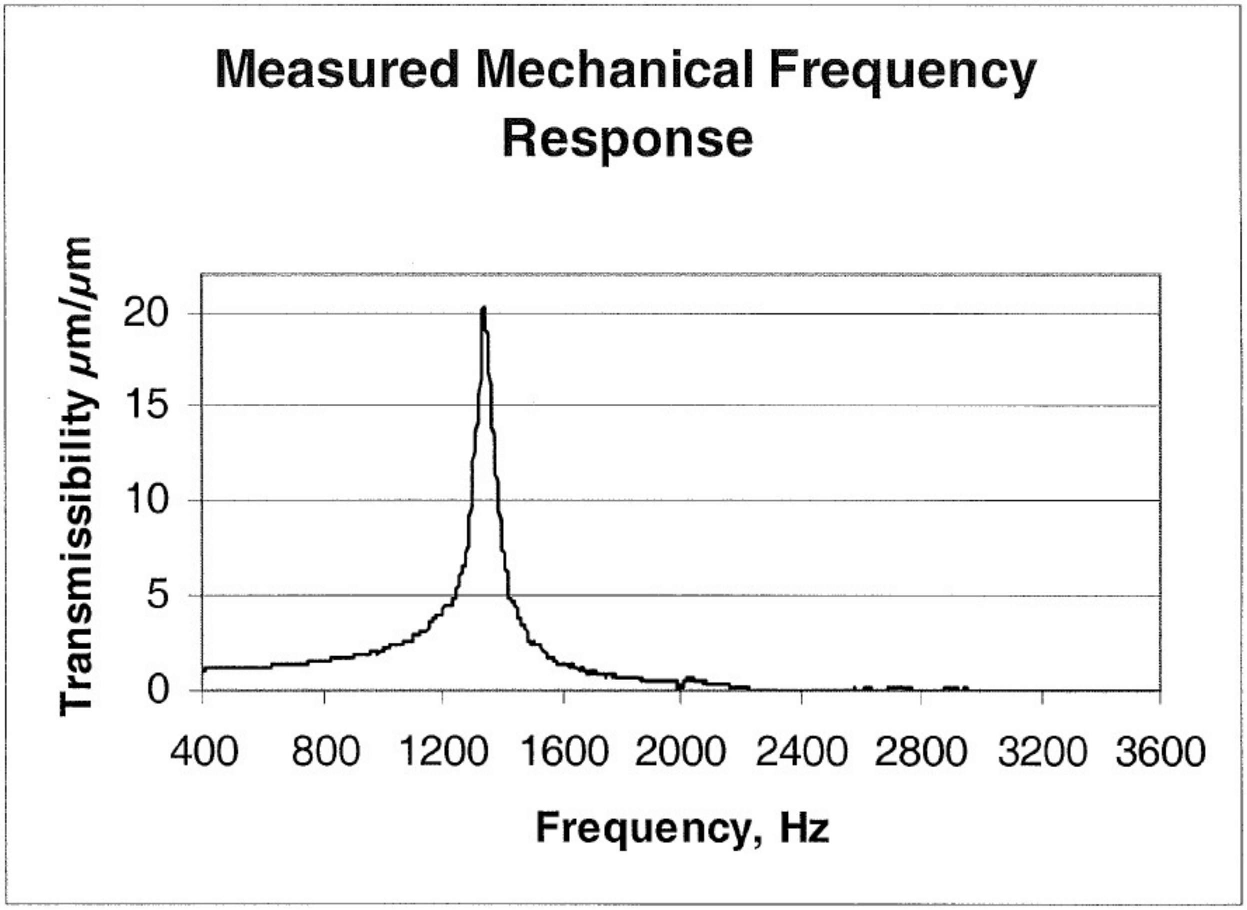
Here is a MEMS device (center square proof mass, two straight beams per side to the surrounding frame). It is held in a plastic holder with a screw on the backside so that it can be mounted onto the electromagnetic shaker. Note: the PCB and the wires in the photograph are from a different project not related to measuring transmissibility. A piece of retroreflective tape is on the proof mass and also on the frame, for reflecting laser beams off at those locations.



Two laser interferometers are used to measure the time varying displacement of the proof mass and the frame:

Another photograph of the system used to measure transmissibility. The equipment on the stand on the left includes the amplifier that powers the electromagnetic shaker, and a dynamic signal analyzer that controls the shaker and processes the output signals from the two laser interferometers to produce the transmissibility plot. Note: the equipment on the table is not used in measuring the transmissibility.

An example measured transmissibility plot of a MEMS device is shown below. Notice that the signal is noisy. Typically, many runs are taken and averaged together, which reduces noise in the transmissibility plot, if the noise is uncorrelated.



What is Q and f_n from this plot?

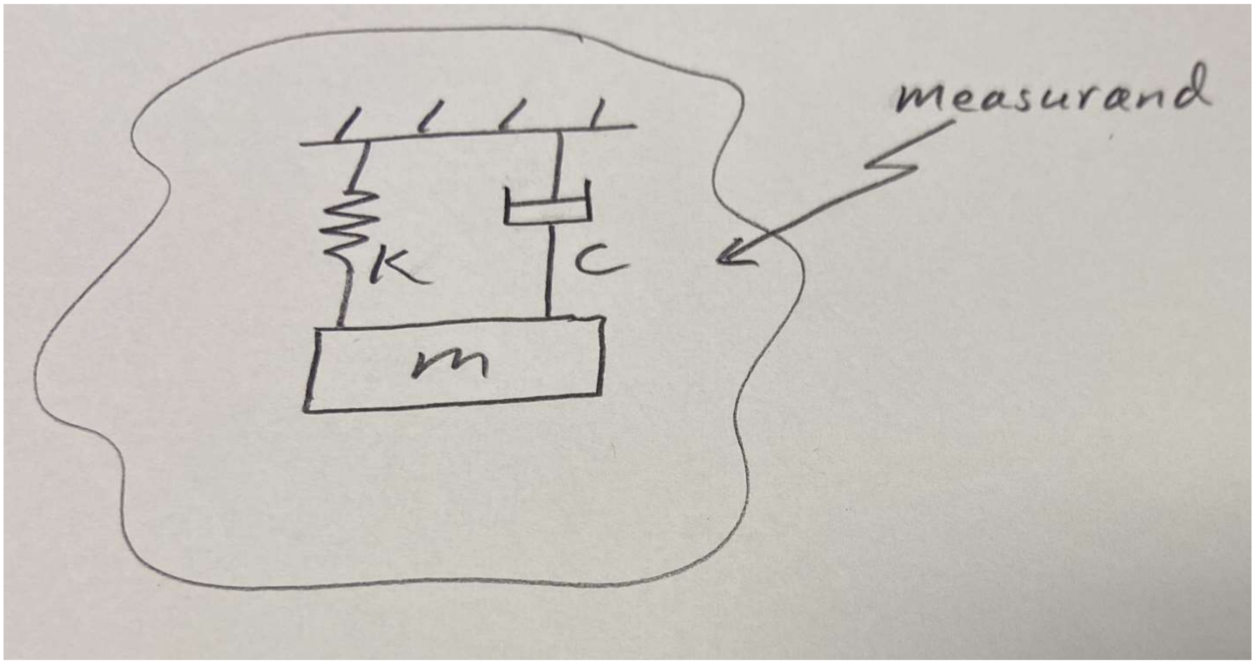
Note, the y-axis CANNOT be in dB to directly read Q off of it:

$dB = 20Log(Q)$ at ω_n.

Sensing Methods

Also called “Transduction Techniques”: textbook chapter 5.

Consider:



The measurand (i.e. the parameter being detected with our sensor) affects something about our MEMS structure, such as m, k, c, proof mass displacement, etc. We need to convert that change in our microstructure to an electrical quantity, such as V, I, R, L, or C:

V, I → optical and thermal sensors

R, C → most mechanical MEMS sensors

L → some macro-scale sensors (ex: LVDT, linear variable differential transformer)

Lecture 9/10/24

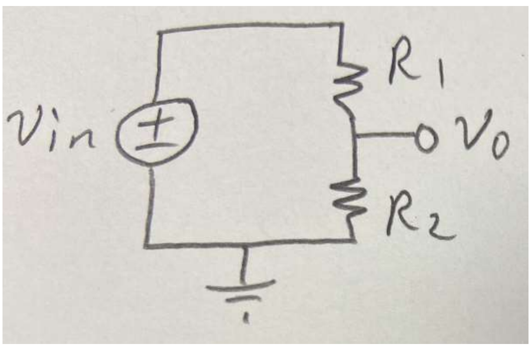
A. Resistance/Conductance Transduction

Converting a mechanical change into a change in resistance or conductance.

First, let's review some related circuit conventions:

1. Review of voltage divider circuits:

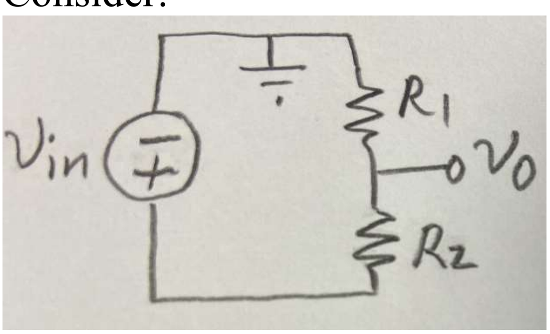
Consider:



$$v_o = v_{in} \frac{R_2}{R_1 + R_2}$$

v_o is the voltage across R_2, referenced to ground.

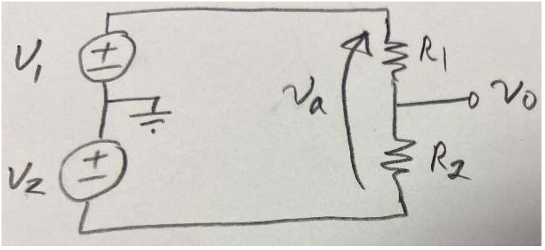
Consider:



$$v_o = v_{in} \frac{R_1}{R_1 + R_2}$$

v_o is the voltage across R_1, referenced to ground.

Consider:

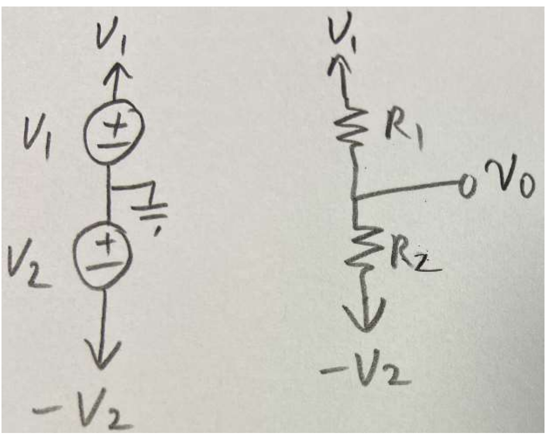


v_o is referenced to ground.

$$v_a = V_2 + V_1$$

$$v_0 = -V_2 + v_a \frac{R_2}{R_1 + R_2}$$

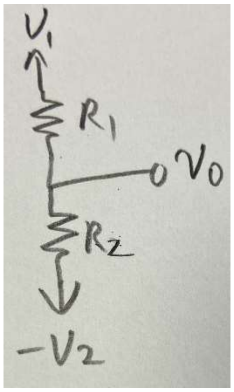
Consider:



The power supply traces are often omitted to keep the schematic diagram less cluttered.

$$v_0 = -V_2 + (V_1 + V_2) \frac{R_2}{R_1 + R_2}$$

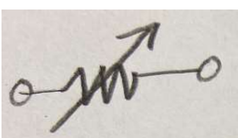
So, since the power supply traces are not shown, we could just define V_1 and V_2 and omit the power supplies from the schematic:



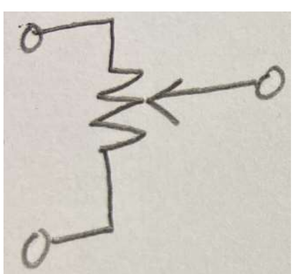
Notice that ground is not shown on the schematic. However, it is defined by the power supplies V_1 and V_2.

And once again: $v_0 = -V_2 + (V_1 + V_2)\frac{R_2}{R_1+R_2}$

2. Interfacing to a variable resistor

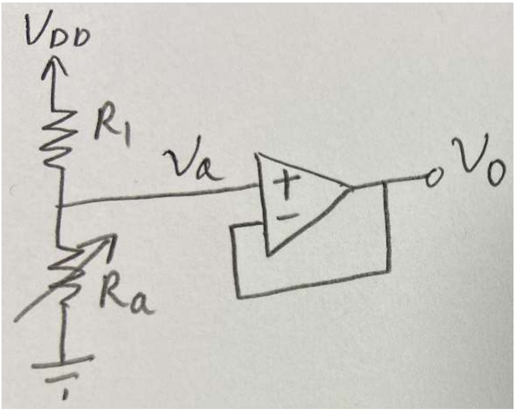


A variable resistor



A potentiometer → useful as a differential voltage divider

Consider:

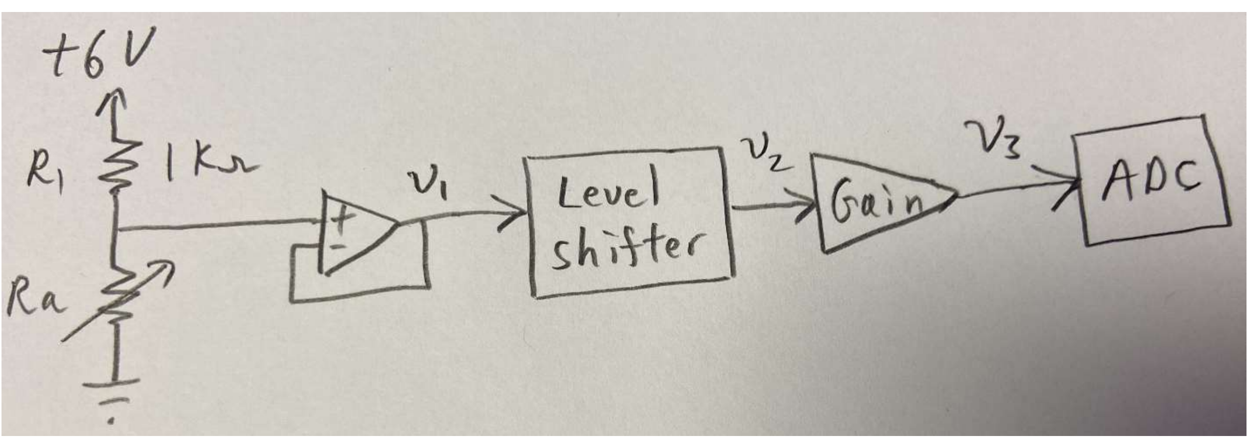


The op amp subcircuit is a unity gain buffer called a voltage-follower. The op amp has a high input impedance, typically ~ 1 MΩ, which doesn't substantially load down the R_1-R_a subcircuit if R_1 and R_a << 1 MΩ. The op amp can then drive a broader range of loads without affecting v_o.

Therefore, $v_o \approx V_{DD} \frac{R_a}{R_1+R_a}$

Consider interfacing a variable resistor to a 5 V A/D converter (ADC):

Ex: variable resistor: 1 kΩ ≤ R_a ≤ 2 kΩ.



$$v_{1mi} = \frac{6(1)}{1+1} = 3V$$

$$v_{1max} = \frac{6(2)}{1+2} = 4V$$

Therefore: 3 V ≤ v_1 ≤ 4 V

Level shifter: shift v_1 by -3 V:

Therefore, 0 V ≤ v_2 ≤ 1 V

Gain stage: use a gain of 5 V/V

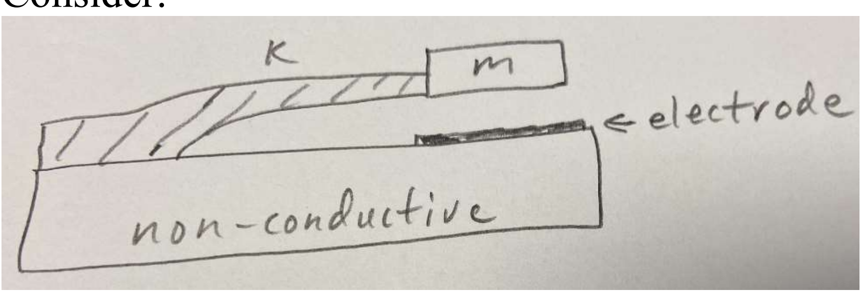
Therefore, 0 V ≤ v_3 ≤ 5 V → this is now the input to the ADC, which maximizes the dynamic range of the ADC.

3. Conductivity Sensing

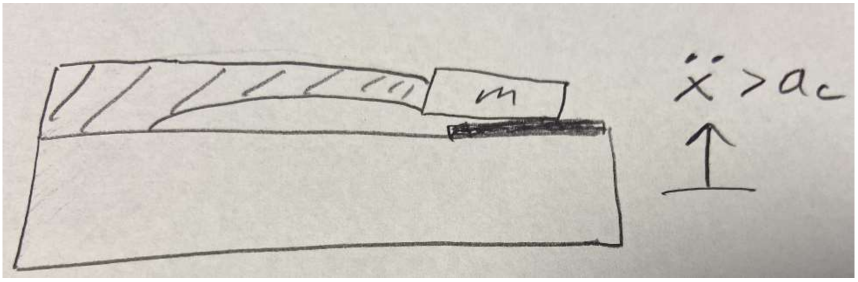
Typically consists of two electrically isolated structures brought into contact by the measurand to close a circuit.

3.a. Example 1: Acceleration

Consider:

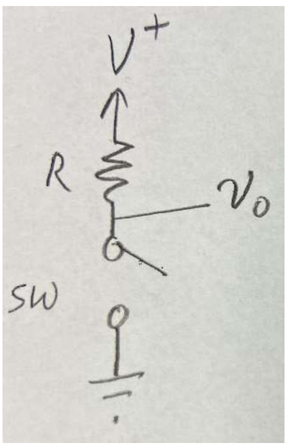


At rest, a gap exists between the electrically conductive spring-mass and the electrode beneath it.



When the acceleration up reaches or exceeds a preset level, a_c, the proof mass deflects down until the two electrodes come into contact, electrically shorting them.

Electrical model for the MEMS device (SW), in series with R:

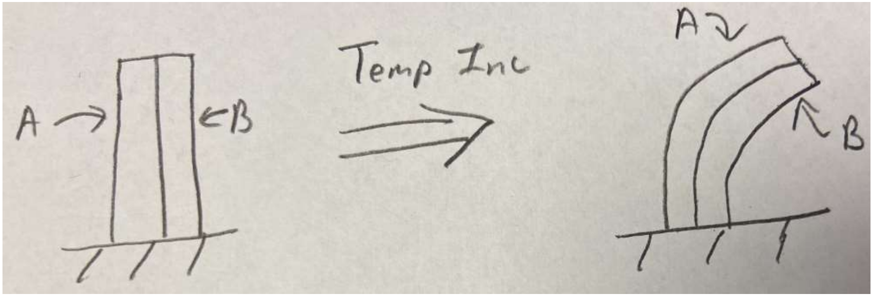


$v_o = V^+ \rightarrow \ddot{x} < a_c$

$v_o = 0V \rightarrow \ddot{x} \geq a_c$

3.b. Example 2: Biomorph Thermostat

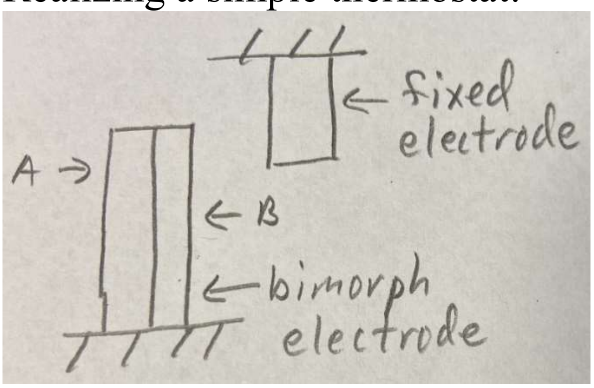
A bimoroph consists of two materials with different CTE's (coefficient of thermal expansion) that are bonded together. When the temperature increases, the higher CTE material expands more than the lower CTE material, resulting in the composite structure bending:



$CTE_A > CTE_B$

Note: it will bend the other way if the temperature decreases.

Realizing a simple thermostat:

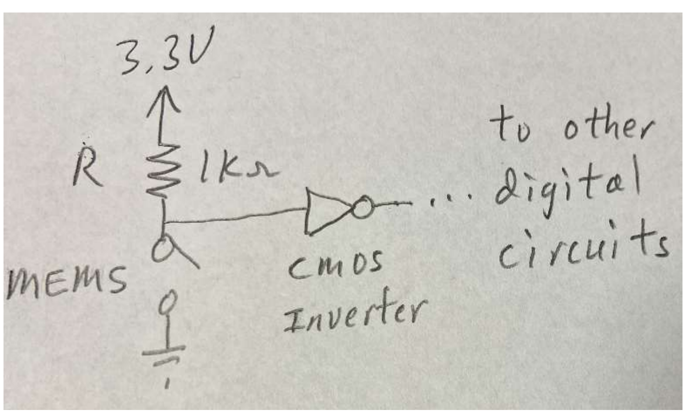


$CTE_A > CTE_B$

The two electrodes make physical and electrical contact for $T \geq T_c$.

3.c. Interface Circuits

i. CMOS inverter circuit

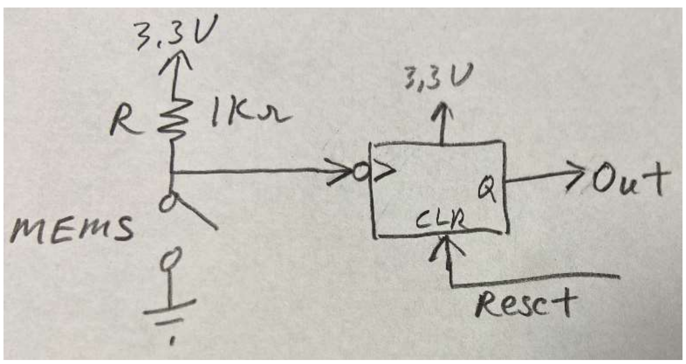


The output of the CMOS inverter can be periodically monitored with a microcontroller digital input, or it could be used to initiate an interrupt.

The low-cost CMOS inverter provides a little bit of isolation between the sensor and the microcontroller. R is a pull-up resistor: $1\ k\Omega \leq R \leq 10\ k\Omega$ is a good range for R. Too low of a resistance will draw excessive current and too large of an R can be electrically noisy.

If the exact time that the sensor changes states is important, a debounce subroutine may need to be run in the microcontroller.

ii. D flip flop circuit

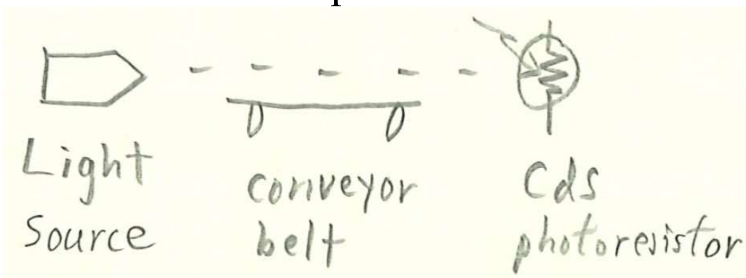


The D flip flop, with an active low clock input, records the event that triggered the MEMS device. It can be read anytime later and then reset. CLR is used to reset the flip flop. Note: never leave a CMOS logic chip input floating (unless it has an internal pull-up resistor). This circuit could serve as a hardware debounce circuit in between the MEMS sensor and a microcontroller.

3.d CdS photoresistor

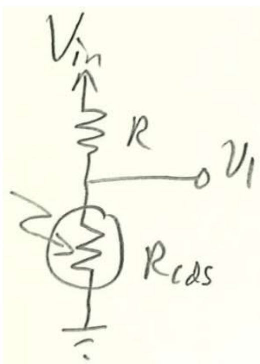
CdS photoresistor → a cadmium sulfide cell: its resistance decreases with increasing light intensity

Consider this example:



Objects on the conveyer temporarily block the beam of light → R_{CdS} ↑

Put the sensor in series with R:

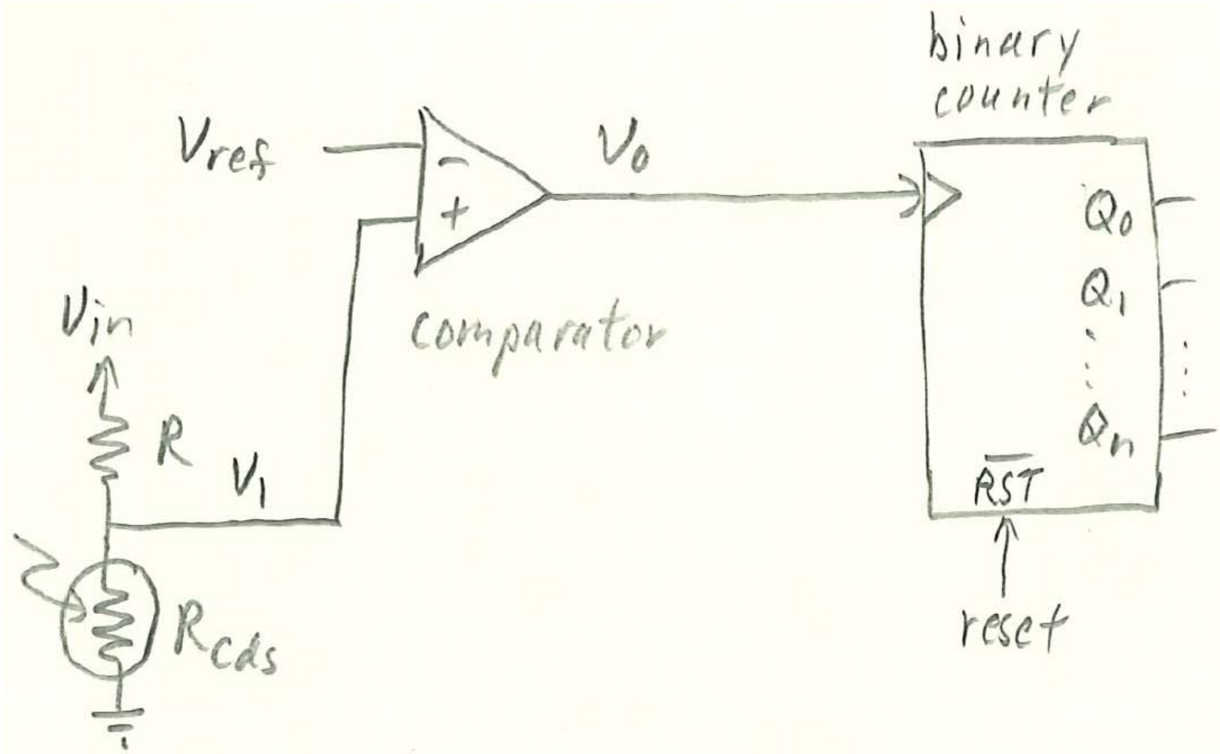


$$v_1 = V_{in} \frac{R_{CdS}}{R + R_{CdS}}$$

Light intensity ↑: R_{CdS} ↓: v_1 ↓

Light intensity ↓: R_{CdS} ↑: v_1 ↑

Now consider this interface circuit:



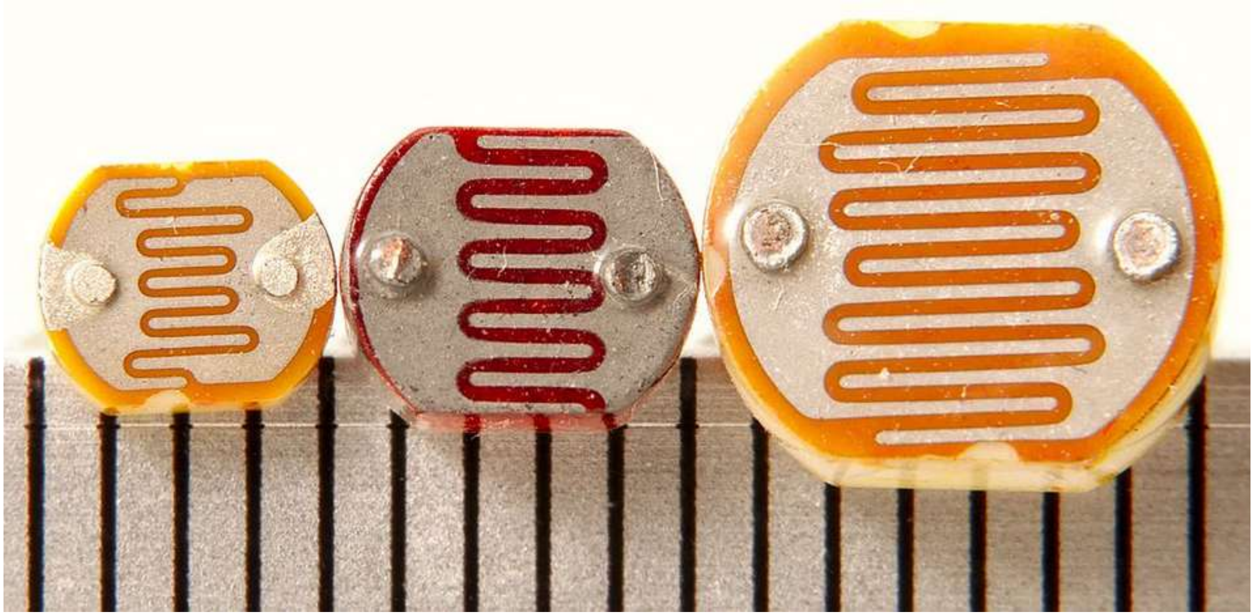
No object in the light path: R_{CdS} low, $V_1 < V_{ref}$, V_o low (logic level 0)

Object in the light path: R_{CdS} high, $V_1 > V_{ref}$, V_o high (logic level 1), counter increments by one

The example above approximates conductivity sensing.

A CdS photoresistor is a semiconductor device that exhibits photoconductivity. CdS is a semiconductor material (usually n-type) and is used in one type of photovoltaic cell. Light above a certain frequency possesses enough energy to free an electron, creating an electron-hole pair to conduct electricity, thereby lowering resistance. R_{dark} can be up to several MΩ, while R_{light} can be as low as several hundred Ω. CdS is highly toxic, a known carcinogen, and is sometimes used in yellow tattoo die.

Three CdS photoresistors next to a mm scale (https://en.wikipedia.org/wiki/Photoresistor)



CdS photoresistors are an older technology, and are relatively low frequency (~10s of Hz response to a change in light intensity). They are fairly low cost.

Example commercially available CdS photoresistor: