Audio and Strain Sensors

ECE 321: Electronics II

Lecture #5

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

Microphones:

There are many types of microphones.

- Some are essentially speakers. From duality, they also produce voltage is you hit them with sound.
- Some are piezo crystals. When you apply a voltage to a piece of quartz, it gets slightly larger. From duality, if you squeeze a piece of quartz (say, with a sound wave), it produces a voltage.
- Some are stain gages on a membrane. As sound waves hit the membrane, it moves, producing stress and strain on the membrane.

Most of the microphones in lab are Electret Condenser Microphones:

Product Index > Audio Products > Microphones > CUI Inc. CMA-4544PF-W

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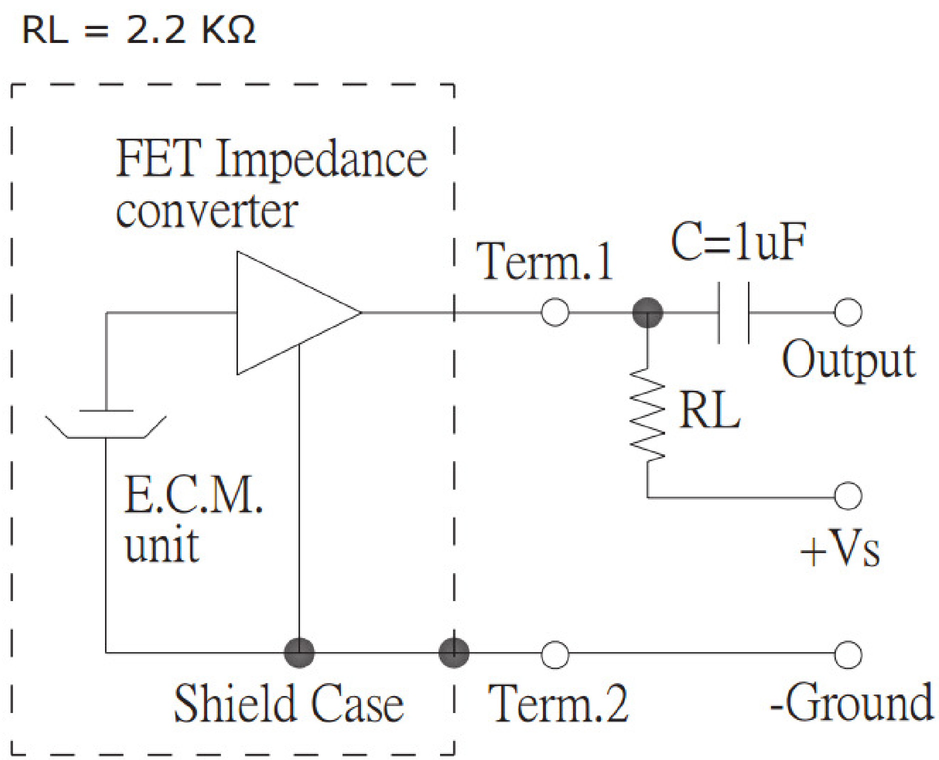
Product Overview	
Digi-Key Part Number	102-1721-ND
Quantity Available	**72,664** Can ship immediately
Manufacturer	CUI Inc.
Manufacturer Part Number	CMA-4544PF-W
Description	MIC COND ANALOG OMNI -44DB
Manufacturer Standard Lead Time	13 Weeks
Detailed Description	20Hz ~ 20kHz Analog Microphone Electret Condenser 3V ~ 10V Omnidirectional (-44dB ±2dB) PC Pins

All prices are in USD.

Price Break	Unit Price	Extended Price
1	0.70000	$0.70
10	0.55300	$5.53
25	0.50240	$12.56
50	0.47000	$23.50
100	0.43750	$43.75
250	0.40000	$100.00
500	0.37250	$186.25
1,000	0.34750	$347.50
5,000	0.32500	$1,625.00

To wire up this microphone, a pull-up resistor is used as per the data sheets:

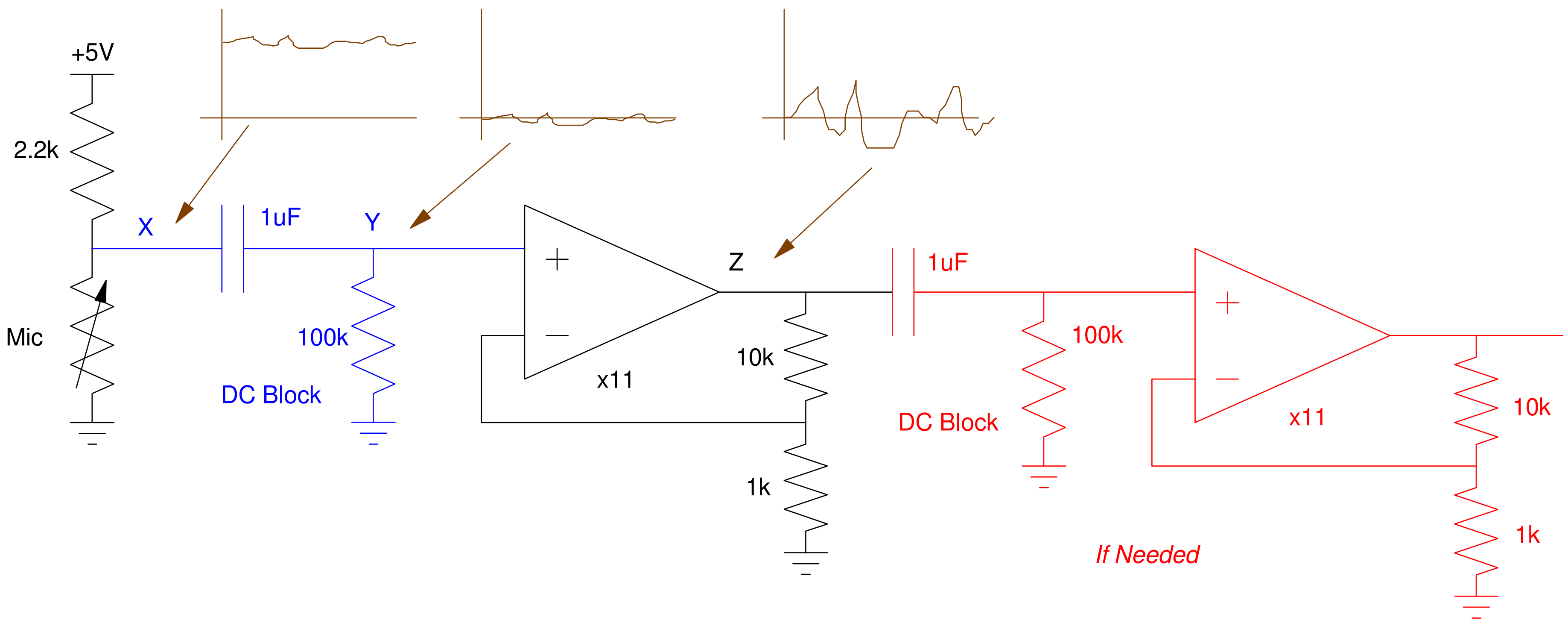
The output signal will be a small (10mV?) audio signal on top of a large DC offset.



Schematic Diagram

To amplify the signal,

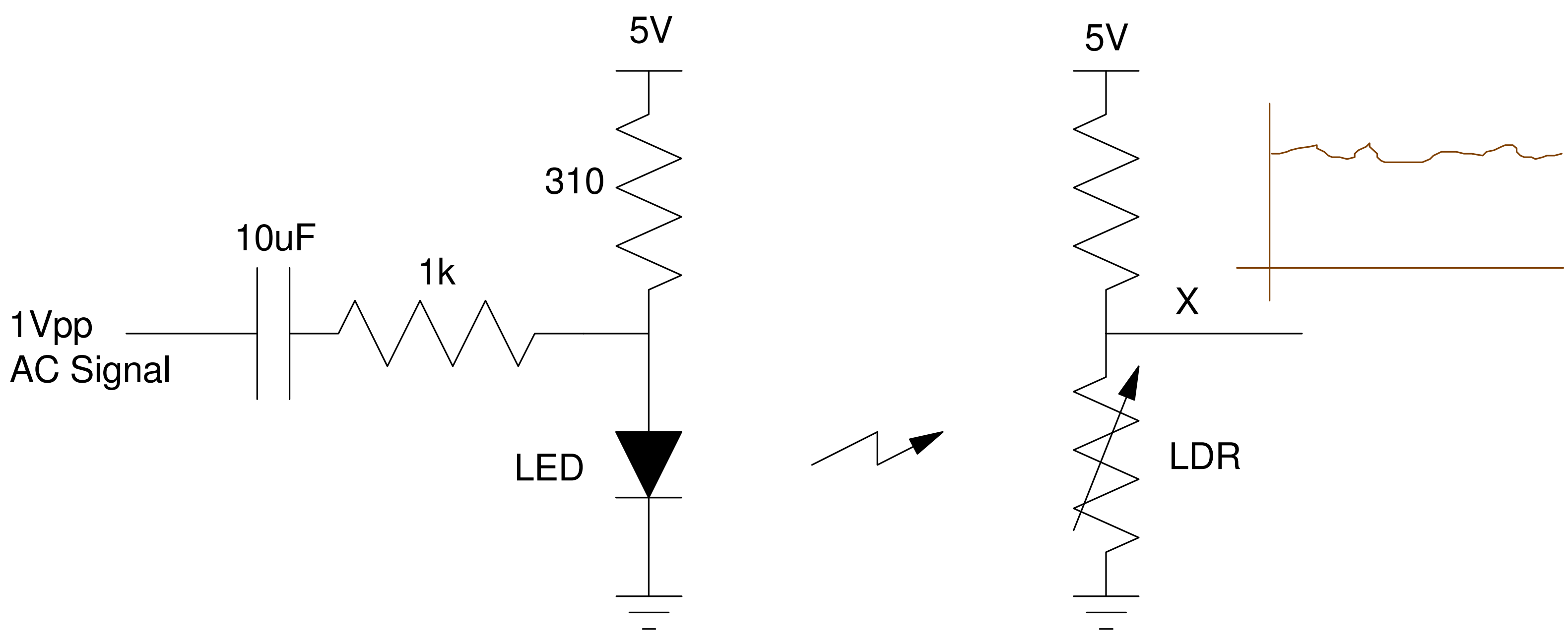
- A DC block is used along with an amplifier
- (note: a speaker can also be used instead of a microphone)



Sound on a Light Beam

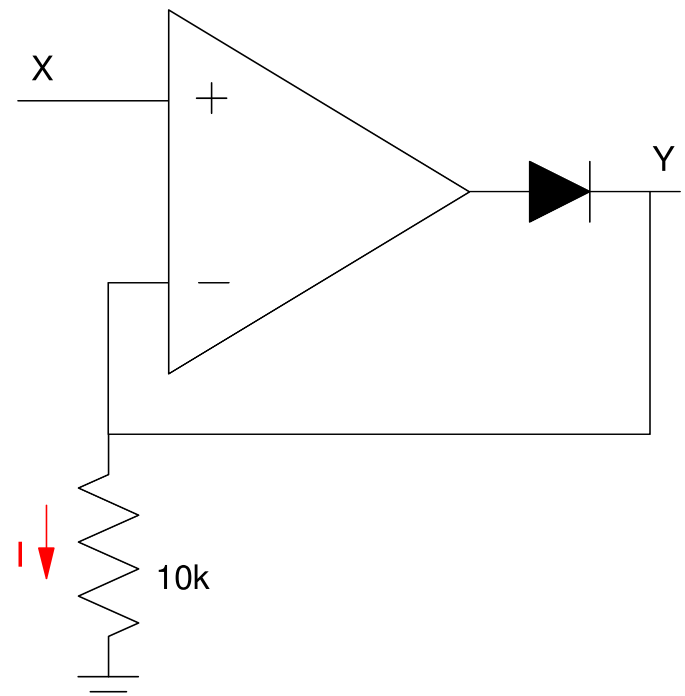
Once amplified, you can transmit the sound on a light beam.

- Bias and LED so that Id = 10mA (Q-point, DC offset)
- Inject an AC signal on top of the 10mA (DC) signal
- Detect the light beam using a light sensor (LDR).



1/2 Wave Rectifier

A diode can be used for a 1/2 wave rectifier, but you lose 0.7V across the diode. With an op-amp, you can remove that 0.7V drop:



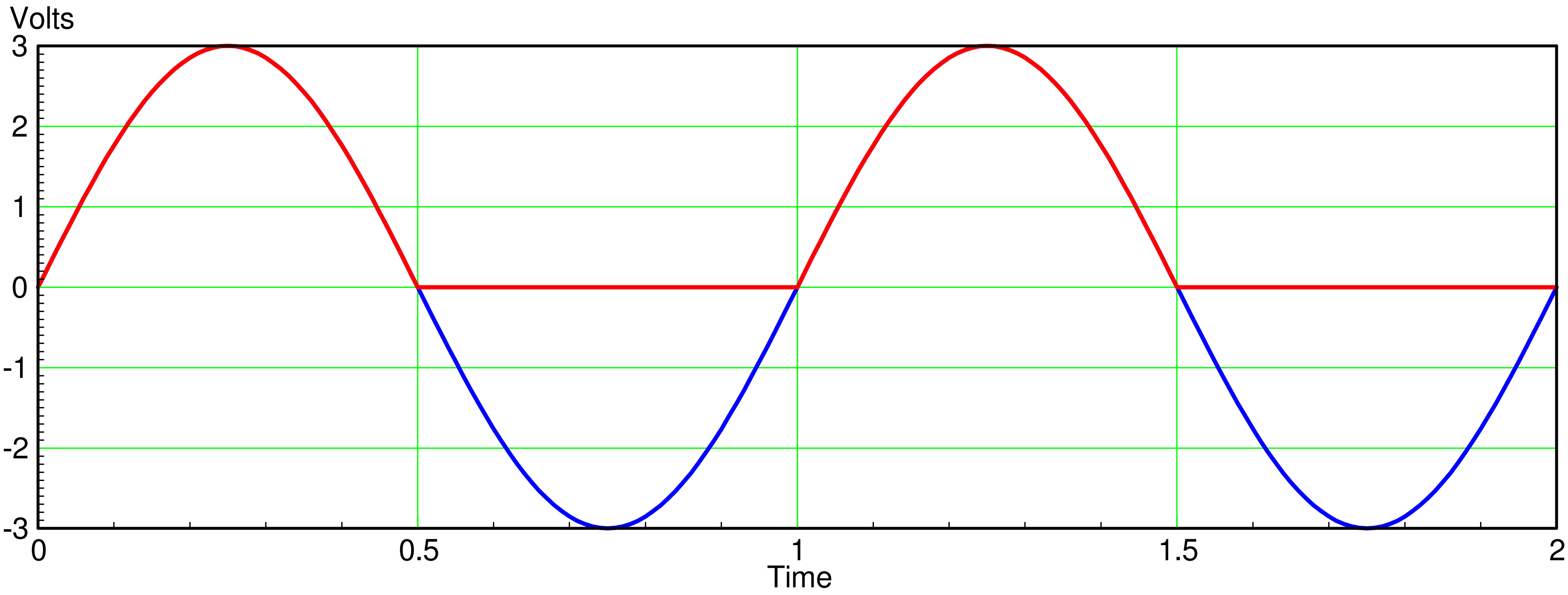
If X > 0

- V+ = V-
- I > 0
- The diode turns on

If X < 0

- The op-amp tries to make V+ = V-
- Which results in I < 0
- Which turns off the diode.

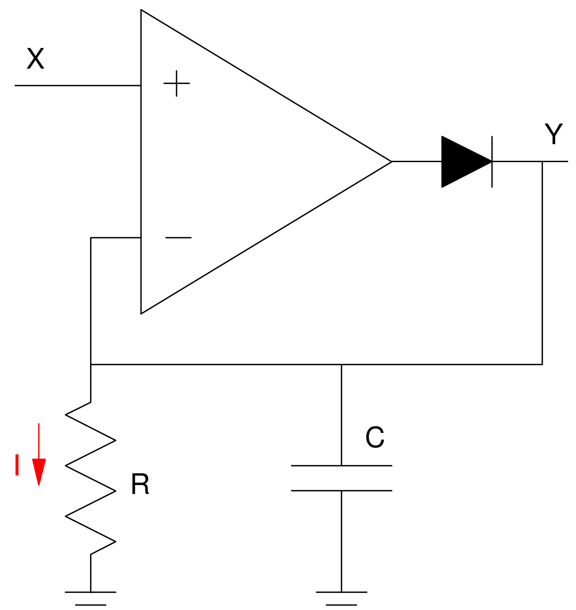
With the diode off, Y = 0



Input (blue) and output (red) for a 1/2 wave rectifier

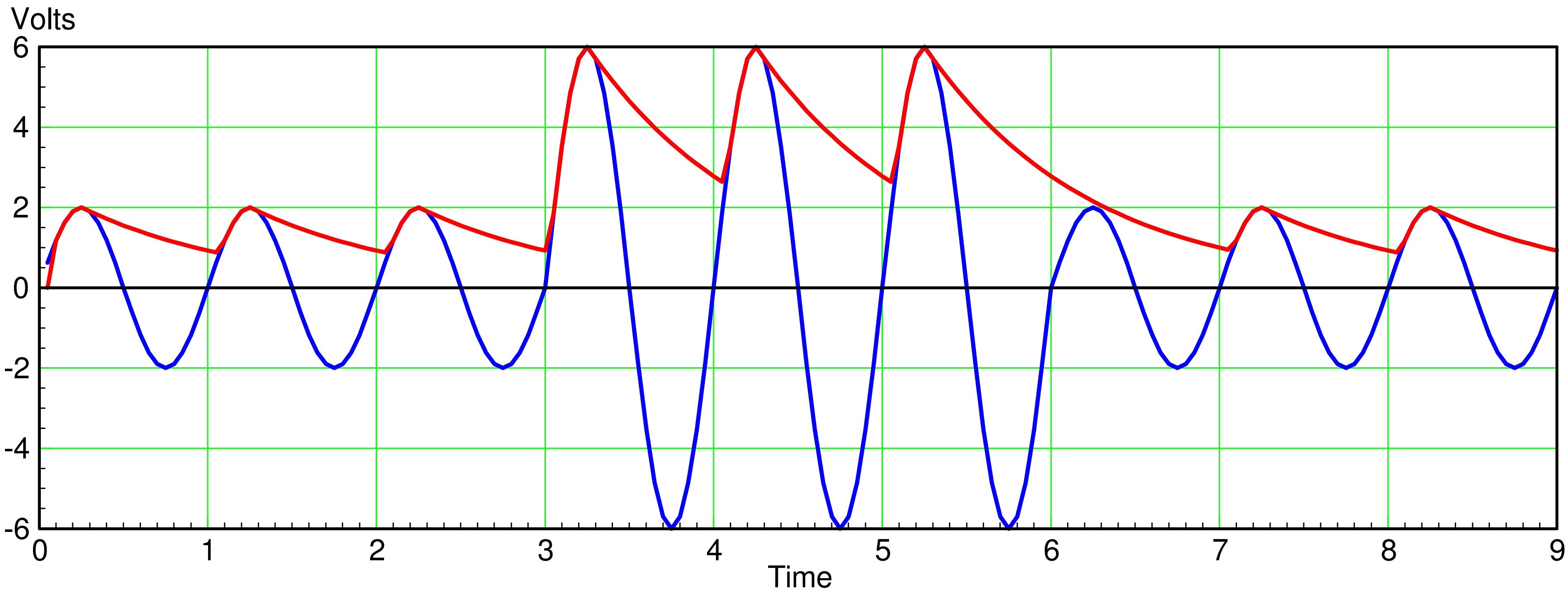
Envelope Detector: If you add a capacitor across the 10k resistor

- When X > Y, the diode turns on, current flows, and the op-amp forces V+ to equal V- (Y=X)
- When X < Y, the diode turns off and the output floats. Y is then the voltage across C, slowly discharging.



The RC time constant tells you how long you hold the voltage at Y:

$$V_y = \alpha \cdot \exp\left(\frac{-t}{RC}\right)$$

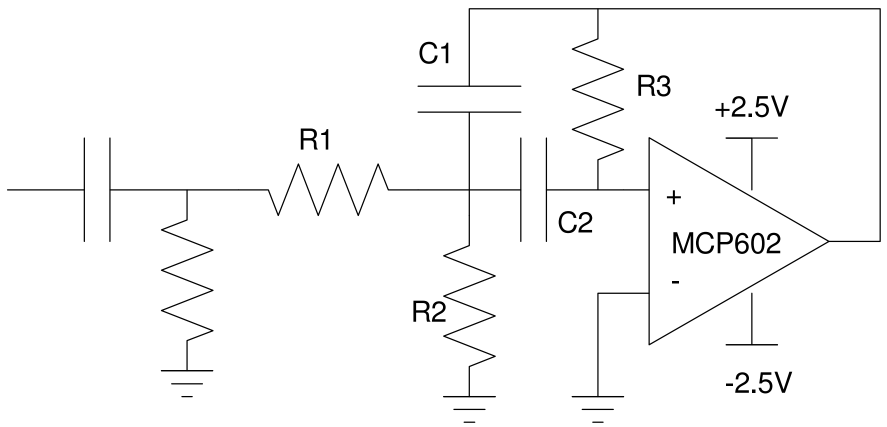


Envelope Detector: The output (red) tracks the amplitude of the input (blue)

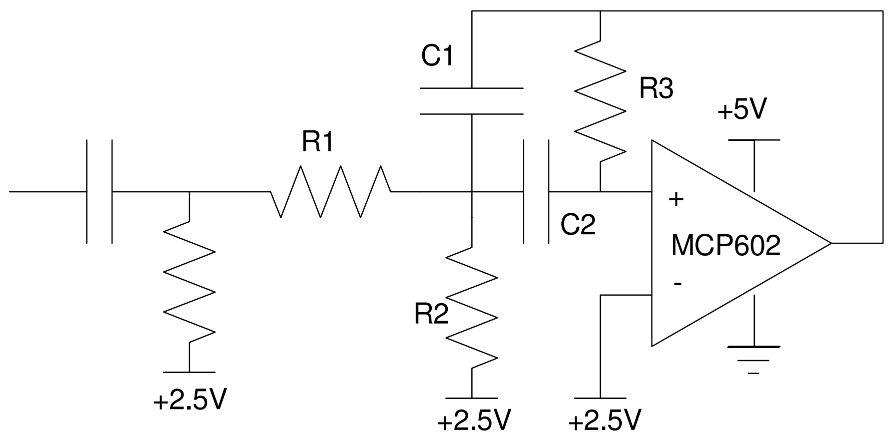
Single-Sided Power Supplies

If instead you only had 0V and +5V available, treat 2.5V as circuit ground

- +5V behaves as +2.5V relative to circuit ground
- +2.5V behaves as +0V (circuit ground)
- +0V behaves as -2.5V relative to circuit ground.



0V behaves as circuit ground



+2.5V behaves as circuit ground

Strain Gages

When you bend a piece of metal, the metal stretches (stress) or compresses (strain). A strain gage measures this change.

Approximate Elastic Constants (from University Physics, Sears Zemansky, and Young, Reading, MA, 1979				
Material	Young's Modulus, (E) 1011N/m2	Shear Modulus, (S) 1011N/m2	Bulk Modulus, (B) 1011N/m2	Poisson's Ratio
Aluminum	0.7	0.3	0.7	0.16
Brass	0.91	0.36	0.61	0.26
Copper	1.1	0.42	1.4	0.32
Glass	0.55	0.23	0.37	0.19
Iron	1.9	0.7	1	0.27
Lead	0.16	0.06	0.08	0.43
Ni	2.1	0.77	2.6	0.36
Steel	2	0.84	1.6	0.19
Tungsten	3.6	1.5	2	0.2

$$Y = \text{Young's Modulus} = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{dL/L} = \frac{\text{force}}{\text{unit change in length}}$$

$$S = \text{Shear Modulus} = \frac{F_{\text{parallel}}/A}{x/h}$$

$$B = \text{Bulk Modulus} = -\frac{dP}{dV/V} = \frac{\text{change in pressure}}{\text{unit change in volume}}$$

$$\text{Poisson's Ratio} = \sigma = \left(\frac{dw}{w}\right)\left(\frac{L}{dL}\right) = \frac{\text{unit change in width}}{\text{unit change in length}}$$

Thin Walled Cylinders

$$\text{Hoop Stress: } \sigma_t = \frac{pD}{2t} = \left(\frac{\text{(pressure)(diameter)}}{2\text{(thickness)}}\right)$$

$$\text{Longitudinal Stress in a Closed Cylinder: } \sigma_l = \frac{pD}{2t}$$

Theory:

The resistance of a long thin wire is

$$R = \frac{\rho L}{A} = \frac{\text{(resistovity)(length)}}{\text{(area)}}$$

If you pull with force F, the length changes as

$$dL = \frac{F \cdot L}{A \cdot E}$$

where E is Young's modulus. The resitance changes by

$$dR = \left(\frac{2\rho L}{A^2 E}\right) F$$

The change in resistance is proportional to the force applied.

Example: Find the change in resistance as you apply a force to a steel wire with Length = 1m, Area = 1mm^2, Force = 0N to 10N

$$\rho \approx 9.71 \mu\Omega \cdot cm \quad \text{resistivity of steel}$$

$$E \approx 2 \cdot 10^{11} \tfrac{N}{m^2} \text{ Young's modulus}$$

$$dL = \frac{FL}{AE} = \frac{(10N)(1m)}{\left(10^{-6} m^2\right)\left(2 \cdot 10^{11} N/m^2\right)} = 50 \mu m$$

The wire stretches 50um with a 10N load. The resistance becomes:

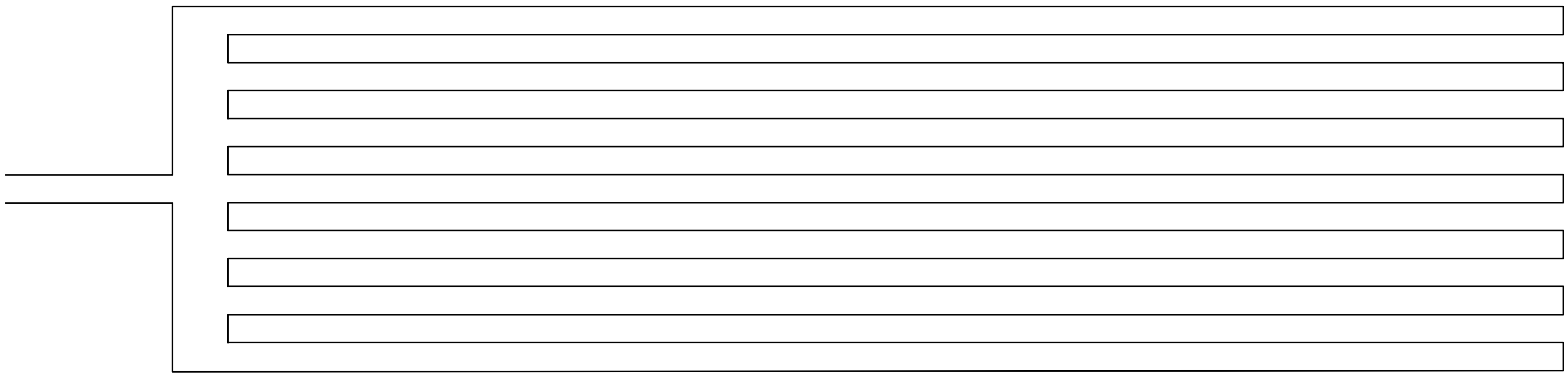
$$R = \frac{\rho L}{A} = \frac{\left(9.71 \cdot 10^{-4}\ \Omega m\right)(1m)}{10^{-6}\ m^2} = 971\Omega$$

$$dR = \left(\frac{2\rho L}{A^2 E}\right) F = \frac{(2)\left(9.71 \cdot 10^{-4}\ \Omega m\right)(1m)}{\left(10^{-6} m^2\right)^2 \left(2 \cdot 10^{11} N/m^2\right)} = 0.00974\Omega$$

R changes from 971 to 971.00974 Ohms.

Design of Strain Gages

To increase the sensitivity, a long wire is required. In order to reduce the size of the strain gage and make it capable of measuring strain over a smaller area, the wire is placed in a zig-zag pattern:



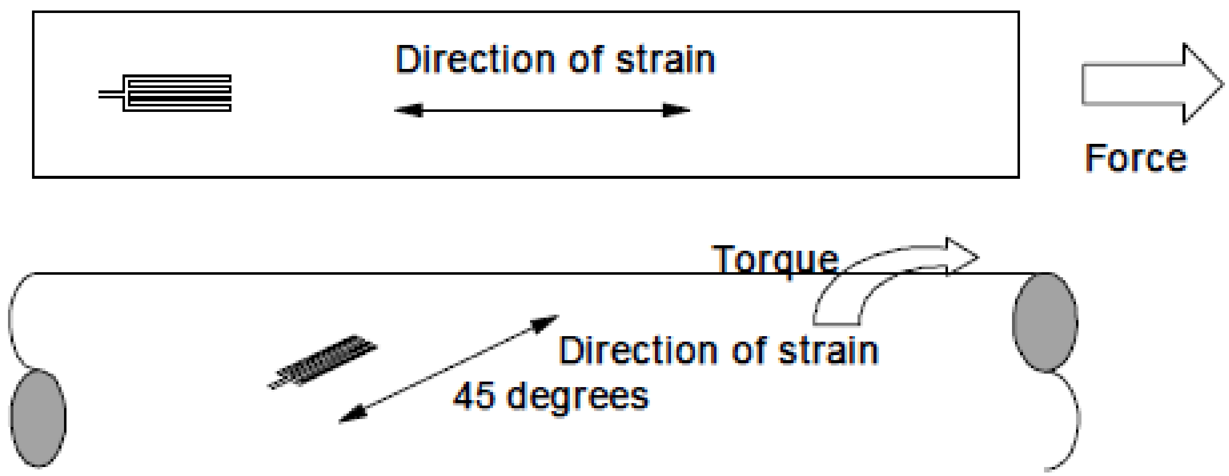
To increase the strength of the wire and electrically insulate it, it is glued to a plastic medium. The main requirements for the glue are that

- It is thin, so that deformation in the material is transferred to the strain gage, and
- It is bonded to the strain gage and the material, for the same reason.

Use of a Strain Gage

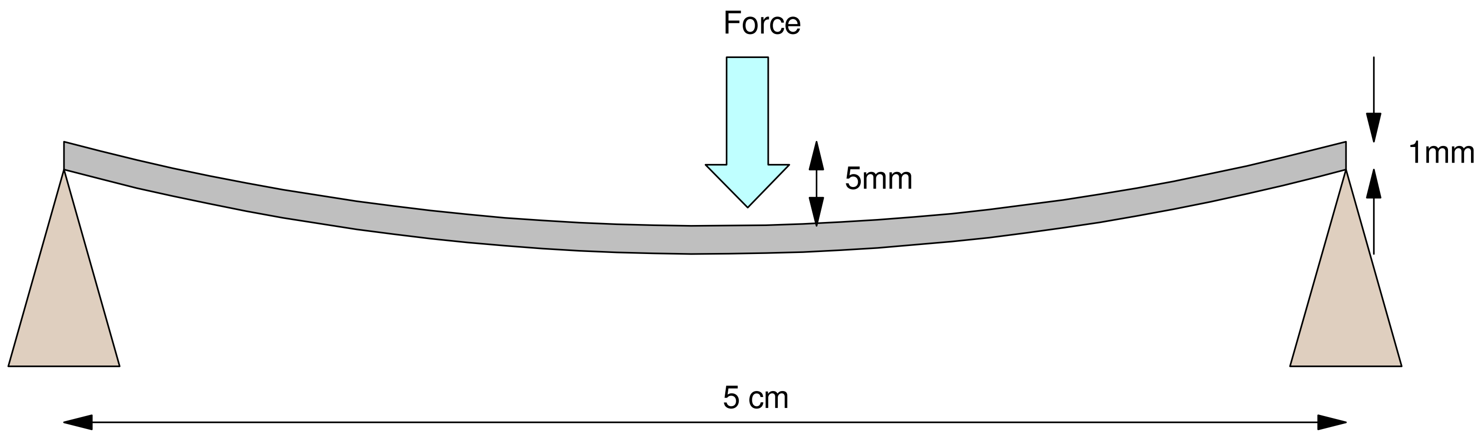
To use a strain gage,

- Place it on a smooth material (to maximize the contact with the mylar coating of the strain gage)
- Place the wires so that they point in the direction of the strain, as follows



- Amplify the bejeebers out of the signal

Example: Find the strain on a piece of metal, 1mm thick, 5cm long, which bows 5mm under pressure.



Solution: First, find the radius of curvature of the beam.

$$R^2 = (R-5)^2 + 25^2$$

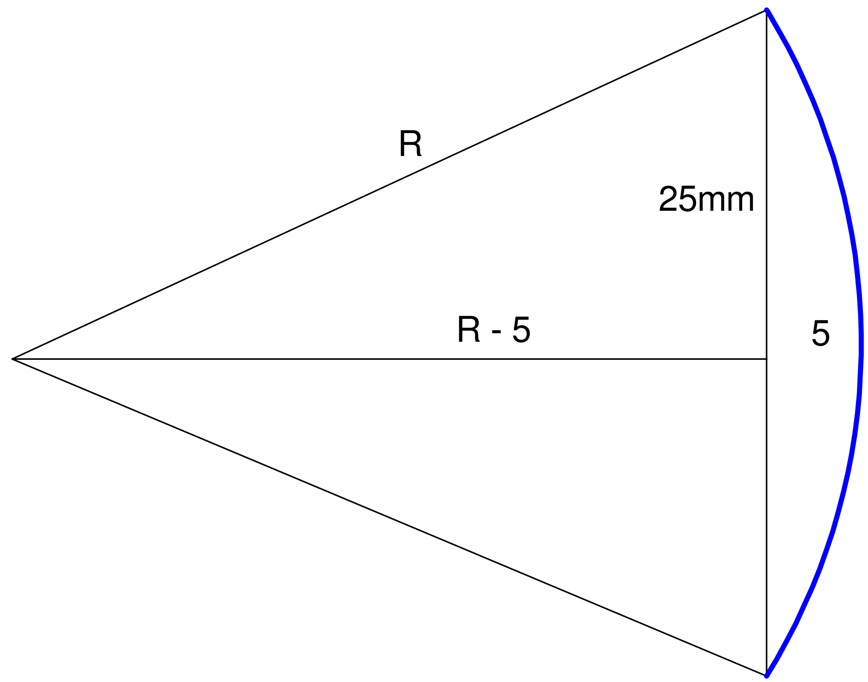
$$R = 65mm$$

Outer Edge Strain:

$$\varepsilon = \left(\frac{65.5mm - 65mm}{65mm}\right) = +0.007692$$

Inner Edge Strain

$$\varepsilon = \left(\frac{64.5mm - 65mm}{65mm}\right) = -0.007692$$



Example: Design a circuit to output 0V at 0 strain and +5V at 7.7mε. Use a strain gage with a nominal resistance of 120 Ohms and a gage factor of 2.14.

Solution: The resistance you're trying to measure is

$$R = 120(1 + 2.14\varepsilon)$$

$$R(0) = 120\Omega$$

$$R(0.0077) = 121.977\Omega$$

Using an instrumentation amplifier and a voltage divider to convert this to 0V to 5V

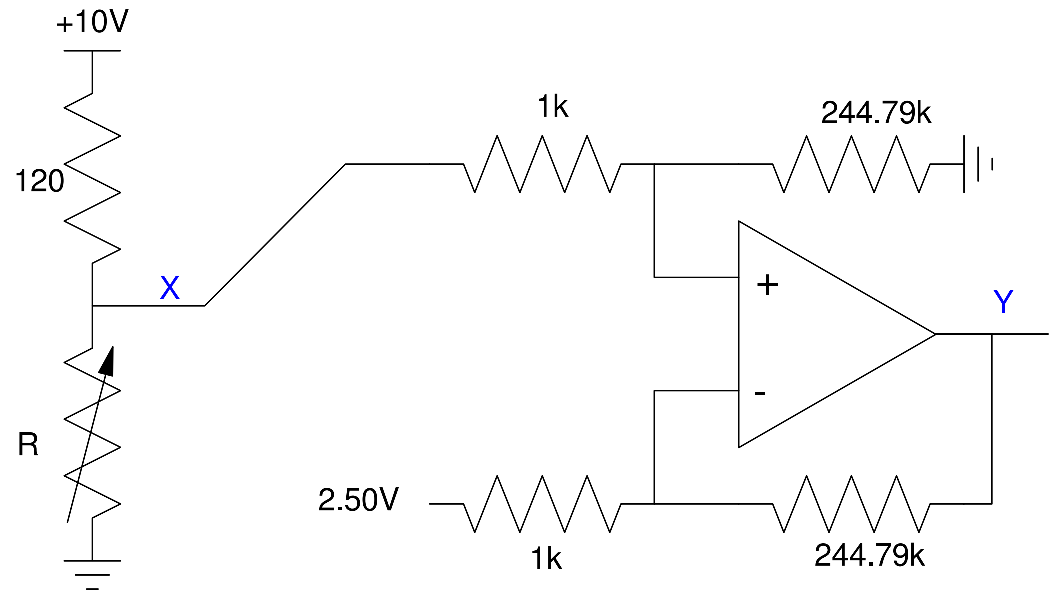
0 Strain

$$X = 2.5V$$

0.0077 strain

$$X = \left(\frac{121.977}{121.911+120}\right)5V = 2.5204V$$

$$gain = \left(\frac{5V-0V}{2.5204V-2.50V}\right) = 244.79$$



Variations:

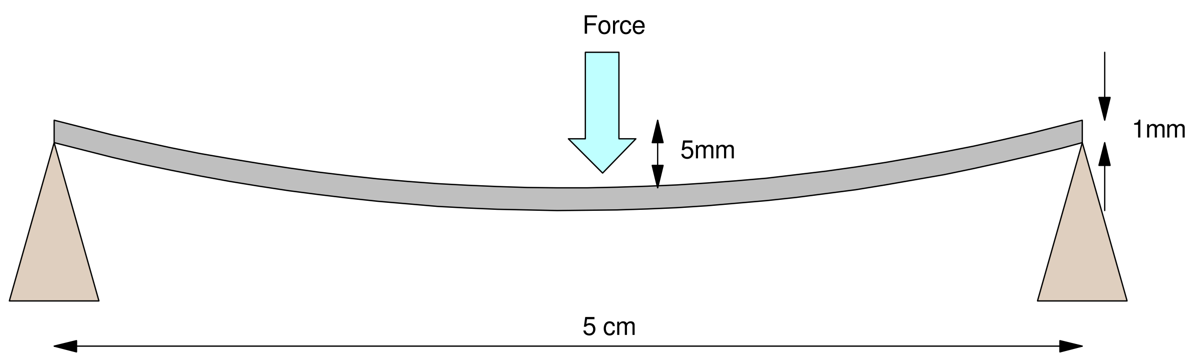
Temperature Compensation: Since resistance also changes with temperature, the output will also change with temperature. To prevent this, replace resistor A with a second strain gage placed on the metal, perpendicular to the direction of strain.

Temperature Compensation with Double the Sensitivity: Replace resistor A with a strain gage placed on the other side of the bar. When one strain gage is under compression, the other is under tension, doubling the voltage change in the voltage divider.

Temperature Compensation with 4x the Sensitivity: Use four strain gages. B and C are placed on the inside surface, A and D are placed on the outside surface.

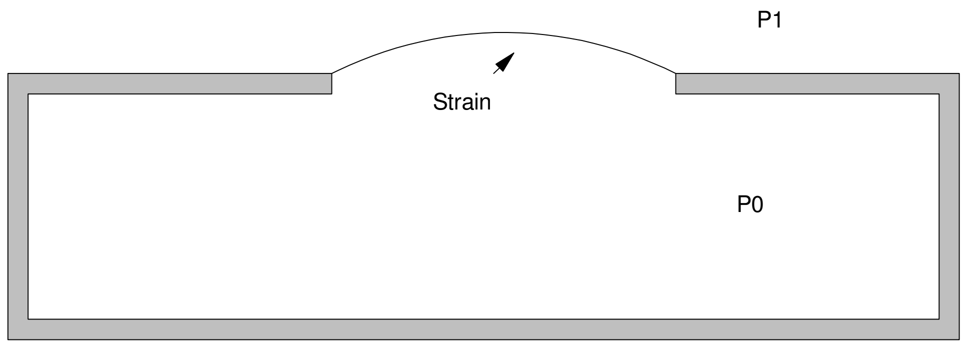
Uses of Strain Gages

1) Force Sensor: Design a mechanical system where strain is proportional to force. This is commonly used in electronic bathroom scales.

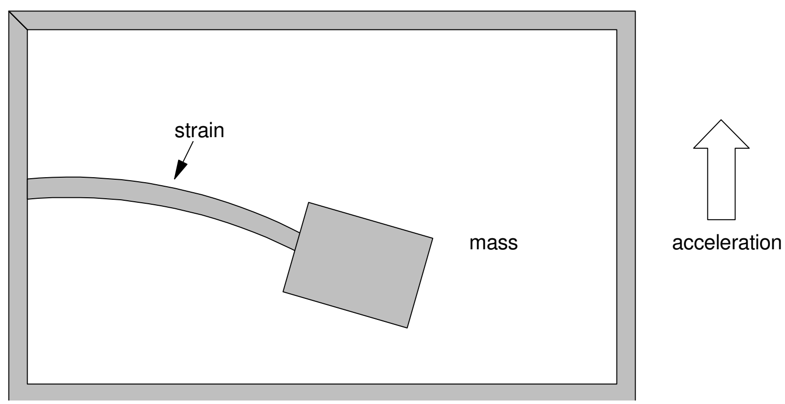


2) Pressure Sensor: Allow the force to be applied over a fixed area. The result measures force per unit area, or pressure.

3) Differential Pressure Sensor: Design a mechanical device where the strain is proportional to the difference in pressure: P1-P0



4) Accelerometer: Design a system where strain is related to acceleration.



Summary

Acoustic Sensors

- Acoustic sensors convert sound to voltage
- An instrumentation amplifier can amplify the signal and remove the DC offset
- If you care about the amplitude of the audio signal, an envelope detector can be added

Strain Sensors

- Convert strain to resistance
- An instrumentation amplifier can amplify the signal and remove the DC offset
- Temperature compensation is often required